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Wildland Firefighter Health and Safety

Recommendations of the April 1999 Conference

Dedication

Arthur H. Jukkala 3/30/35–7/12/99

This report is dedicated to the memory of Arthur H. Jukkala, an MTDC employee who spent his career working to improve the health and safety of wildland firefighters. As program leader for the fire and safety and health programs, he was responsible for the development of uniforms, personal protective equipment, tools, nutrition, hydration, fitness, employee health, and other health and safety projects. After his retirement in 1990 he served as consultant on the development of the Pack Test, and was active in the Smokejumper's Association. Family, sculpting, woodworking, travel, and vigorous outdoor pursuits filled his retirement years. He came to rest in his favorite place, the Bob Marshall Wilderness, while leading a volunteer trail crew composed of exsmokejumpers.

Wildland Firefighter Health and Safety

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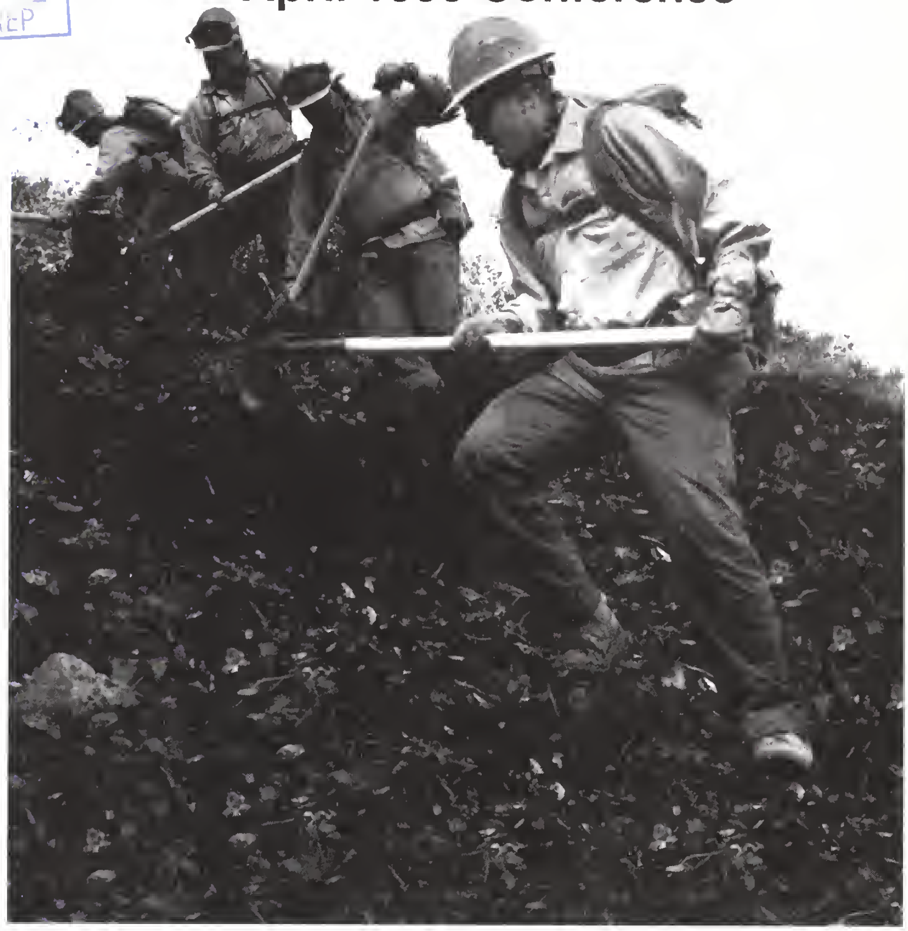

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9E92P47—Wildland Firefighter Health and Safety

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Introduction

Wildland firefighting is arduous work, performed for long shifts in difficult environmental conditions. The work can be dangerous, due to the fire and the working conditions. Heat, smoke, rolling rocks, falling snags, and other hazards threaten the worker. Those hazards include mountain travel, sharp tools, heavy loads, and aerial operations. Fatigue can impair performance and decision making, increasing the risk of injuries. Prolonged exposure to fatigue, stress, smoke, and poor nutrition has the potential to increase the incidence of upper respiratory illness and other illnesses.

Since the 1960's, the Missoula Technology and Development Center (MTDC) has been involved in projects related to the health and safety of wildland firefighters. Past work has involved field studies of the metabolic, cardiovascular, and thermal strain associated with the work, uniforms, heat stress, hydration, nutrition, work/rest cycles, smoke, and other factors related to firefighter safety, health, and performance. MTDC has developed two generations of work capacity tests and training programs for firefighters, and employee health (wellness) programs for agency employees.

The National Wildfire Coordinating Group (NWCG) coordinates wildfire activities among federal and State agencies throughout the United States. Its Safety and Health Working Team (SHWT) oversees the safety and health of wildland firefighters. On April 27 to 29, 1999, the SHWT and MTDC cosponsored a national conference to explore ways to enhance the health and safety of wildland firefighters. The conference, held in Missoula, featured invited speakers, panel discussions, and open forums designed to identify and discuss current and emerging issues. Based on the presentations and discussions, conference participants met in working groups to develop recommendations. The recommendations are intended for immediate implementation, for field evaluation, or for future research and development. This report includes the papers presented at the conference, and the recommendations of the conference participants.

Recommendations

Following the presentation and discussion of information, conference participants met in working groups to formulate recommendations. The working group recommendations were shared with the conference participants. Following discussion, the working groups finalized their recommendations.

Illness, Injury, and Fatality Prevention

Recommendations were formulated in the areas of Care, Training, and Information.

Care

Provide a higher level of care in fire camp:

- to reduce costs (direct and indirect), transportation, and lost wages,
- to provide better care, quicker diagnosis, reduce exposure.
  - *Develop criteria: using industry standards to determine when to request a care giver (i.e., 400 to 500 people), or on contract to request as needed.*

Care Giver (Registered Nurse, Physician's Assistant, Nurse Practitioner) to fit local jurisdiction or state practice. Develop protocols to provide treatments (i.e., upper respiratory infection, poison oak, hydration, etc.). Consider ability to prescribe medications, administer injections, suture.

Injury, illness analysis process:

- accidents/illness as related to types of employees (AD's, volunteers, temporaries, etc.)
- determine if changes are necessary as a result of the analysis.

Training

- 29 CFR 1960 or equivalent for managers and supervisors (Supervisor Responsibilities),
- Integrated behavior-based safety model (shift from compliance-oriented process),
  - *Use theories of safety psychology*
  - *Use practical tools and systems to implement a structured observation and measurement process*
  - *Include management and employees in the process*
  - *Use zero accidents and injuries as a goal.*
- Crew supervisor training
  - *Leadership training*
  - *Communication training*
  - *Behavior-based theories and tools*
  - *Making of a crew (MTDC)*
- Vehicle operator training course and implementation (available at fire camp for volunteers and AD's)

Information

The National Wildfire Coordinating Group (NWCG) Safety and Health Working Team (SHWT) should summarize up-to-date fire fatality information, suggest a new means of distributing that information, and verify that the information is being received. The target group is ground level with an emphasis on nonfederal agencies (e.g., volunteers and rural fire departments).

Using the distribution process indicated above, the SHWT should develop an information packet of publications and materials annually and distribute the packet throughout the wildland fire community, with an emphasis on nonfederal agencies. Packet contents could include information on NWCG standards; personal protective equipment; incident command system organization/qualification; health and fitness; fire training courses; illnesses, injuries, and fatalities. The SHWT should review the packet annually and be responsible for distribution of the packet as indicated above.

To minimize accidents and capture information on potential hazards and near misses, a reporting system such as the SafeNet Program (currently scheduled to be beta tested in the Forest Service's Pacific Northwest Region (6) should be developed.

Job Requirements/ Issues

The group examined job requirements and related issues that affect firefighter safety and health. The following issues were brought forward by the group.

Assignments

The workgroup recognizes numerous issues related to assignment requirements including assignment length, rest and relaxation (R&R), assignment flexibility, shift length, work/ rest ratios, availability/participation.

These issues can be divided into two groups:

1. Those that relate directly to the physical well-being of individuals such as issues that affect fatigue; and
2. Those issues that are related to personal/cultural/organizational factors.

Group 1 issues include assignment length, rest and relaxation, shift length, and work/rest ratios. These issues are probably best handled through research.

The following specific issues should be addressed:

- a measure of fatigue/alertness
- cumulative effects of fatigue
- longer recuperation periods at home between assignments
- effects of assignment type (line, camp, aviation, etc.)
- frequency and severity of injury, and when most injuries occur
- literature search for statistics and related studies that have already been completed
- shift length
- travel time included in assignment length
- effects of preassignment activities (e.g., prescribed burns)
- quality of rest period
- what constitutes rest—what is appropriate for proper rejuvenation?
- emergency vs. nonemergency/ routine job assignments and proper work rest cycles.

Group 2 issues include assignment flexibility and availability/participation. Long assignment requirements and other issues create barriers to many who would otherwise participate in fire suppression activities. Family and work demands affect safety directly by creating stress and indirectly by preventing people, often those with considerable experience, from accepting fire assignments.

This workgroup recommends that the following issues be examined:
a) Barriers that prevent people from taking part in fire activities. How can we chip away at these barriers to induce more people to take part? (Examples: stress on marriages, stress from leaving children for long periods, line officers who are reluctant to allow employees to leave home units).
b) Alternative approaches for assignment length.
c) Cost and logistics of flexibility (pro and con, e.g., travel costs may rise, but managers may see more experienced workers, experienced workers require less training, there is less fatigue if more people are taking part, employees may be happier, etc.)

Crew Typing

Problem: Need to raise Type II crew standards. Is this done by changing Type II requirements, or adding more crew types so Type II performance is more consistent?

Recommendations: Task IOS (Incident Operations Standards) Team to improve Type II Standards. Examine experience levels, qualifications and equipment requirements.

Driving Regulations

Problem: The way in which driving regulations are interpreted and applied during emergency situations is inconsistent between agencies.

Recommendation: This group recommends that a national standard be established for all agencies. The FFAST (Federal Fire and Aviation Safety Team) group is believed to be addressing this issue.

Fitness Requirements

Problem: Maintaining fitness among full-time fire employees, returning seasonal employees, and nonfire employees who take part in fire suppression activities (militia).

Recommendation: Agencies should require mandatory participation in fitness programs **at a minimum** for seasonal and full-time fire employees. Questions arose regarding the ability to require participation by nonfire employees and the ability to pay for health club memberships for temporary employees.

Contract Resources

Problem: Quality of contract resources is inconsistent.

Recommendation: Emphasize need to follow set policy in contract administration.

Medical Standards

Problem: Current fitness standards do not address existing medical problems that may lead to injury.

Recommendation: Support medical standards relative to incident management positions and encourage ongoing efforts regarding medical screening.

Training and Certification of Work Capacity Test Administrators

Problem: Question arose regarding the need to certify Work Capacity Test Administrators.

Recommendations: Wait for recommendations from Work Capacity Test investigations.

Minimum Qualifications

Problem: The work group recognizes that some full-time fire managers lack adequate fire qualifications.

Recommendations: The group supports the Interagency Fire Program Qualifications Task Group and suggests that States also identify their own Program Management Qualifications.

The Working Environment

All incident personnel shall be informed of the hazards related to their working environment and shall be appropriately trained and provided with the equipment to safely deal with those hazards.

Heat

- Consider using both a.m. and p.m. shifts. If p.m. shifts are used, locate crew camps away from main base camp, generators, etc. (use spike camps, mini-base camps, etc.) If night shifts are used, the terrain should be sized up for snags and other hazards so crews can be made aware of their locations before the start of their shift.
- Ensure that breaks are being taken by the crews. Educate crews on the importance of breaks. Make sure individuals are not penalized for taking a break to recover from heat-related problems.
- Ensure that crews are educated about acclimatization, heat-related illnesses, and that they are acclimatized to the environment as much as possible before they are asked to perform the most strenuous tasks at a fire.
- When crews are assigned a task, make sure their level of acclimatization is taken into consideration.
- The Safety Officer for the fire should prep the crews once they arrive at the fire about the environmental conditions (heat) and remind them about heat-related illnesses and acclimatization.
- Develop a checklist related to heat stress for the dispatcher to provide for crews before they arrive at a fire.
- Investigate the use of Rehab tents by the Medical Group Unit to help crews recover from working in the heat.
- Use motels and air-conditioned tents for crews at fires. This is especially important if night crews are used. The ability to use this will vary upon the geographical location of the fire and the costs involved. At the present time, Florida puts crews in motels when they are fighting fires in the State.
- Ensure that crews are hydrated properly to work in the heat.
- Investigate the use of personal cooling systems (such as cooling vests) by crews, their effectiveness, ease of use, etc.
- Continue to research the development of Nomex garments that do not increase the worker's heat load.
- Investigate the effect of working a night shift or work/rest cycles on the crews.

Smoke

- Mitigate the effects of smoke by avoidance–both by placement of camps and tactics used to fight fires.
- Educate crews about the hazards of smoke.

- Ensure that present smoke conditions are communicated to the crew from the base camp. The crew also needs to ensure that they communicate their present smoke conditions to the base camp.
- Review exposure data/health data (both acute and chronic, on and off the job) related to exposure to smoke.
- Investigate if high smoke exposure times are predictable.
- Collect smoke exposure data using dosimeters. Review exposure data that are collected.
- Conduct pulmonary tests on crews before and after exposure to smoke to determine effects on crews.
- Research the need for crews to wear respiratory protection—investigate smoke versus dust.
- Research the type of fuels crews are exposed to and determine if smoke is hazardous to the crews.
- Research the need for protection from super-heated gases.

Uniforms

- Ensure that the appropriate PPE is not only provided to the crews but is worn by them.
- Establish a mechanism (e-mail) to share research and development between individuals completing research on uniforms for firefighters.
- Study the type of boot that is appropriate for crews to wear; ensure that appropriate boots are being purchased.
- Establish a method for crews to get comments regarding personal protective equipment to the Missoula Technology and Development Center (MTDC).
- Consider a postcard that the crews can pick up when they going through the food line.
- Continue research to ensure that women are provided with Nomex pants and shirts that are sized properly for them.
- Continue discussion with textile manufacturers on the development of new Nomex fabrics; development of fabrics that have better breathability is especially important.
- Review the design of the fire pack and ensure that it can be adjusted so it fits a wider percentage of the population. Allow individuals to have fire packs custom made if they have approval.
- Investigate the performance/comfort issues related to boots.
- Research using reflective tape or markings on the Nomex garments for visibility.
- Research the visibility of the different colors of helmets that are worn and see if helmet color affects the safety of crews.
- Research if the cost of boots can be financed by the Forest Service so that individuals can afford a better boot when they start fighting fire.

Tools

- Ensure that crews are trained properly to use, carry, and repair hand and power tools.
- Ensure that manufacturer specifications are followed when repairing tools.
- Share information on safety issues under "Tech Tips" published by MTDC on alternative PPE products and approaches (such as use of a chain saw harness).
- Review the tools currently being used to determine if their size is appropriate for the current work force.
- Research the difference between fiberglass and wooden handles on tools.

Energy, Nutrition, and Health

Definition of the Issues

1. Compromised nutrition was found in the majority of tested subjects (in terms of total macronutrient intake patterns).
2. The working environment contains all of the factors known to challenge or compromise immune function.
3. Further education of the caterer organizations and firefighters is needed.
4. Special training and/or information needs to reach wildland firefighters in camp on the types of food they need to eat and how much food they require.
5. The concept of eating and drinking to meet the physiological demands (rather than eating and drinking according to personal preference) needs to be taught.
6. It is unclear what factors in the fire diet and work environment predispose wildland firefighters to weight loss, but they may include: a conscious choice to lose weight, unavailability of the right foods, and eating fatigue that develops from the caloric demand.

Recommendations–Research and Development:

Topics for recommended research and development include:

- Tray survey to identify self-selected dietary selection and intake on the fireline.

  The purpose of this study would be to describe the dietary availability and the actual consumption patterns of the wildland firefighter (what is available vs. what is consumed). The goal would be to describe the existing meals (macro/ micronutrients), actual consumption, and define areas in need of improvement. Issues related to vegetarians and gender should be considered.

  A secondary purpose would be to perform a qualitative study to identify common misconceptions in the wildland firefighter community on what foods should be consumed to maintain health and maximize performance.

- Review the reported dietary intakes of firefighters in total energy expenditure (TEE) studies to determine:
  - *macro/micronutrient intake patterns (% of total, g/kg for carbohydrate and protein)*
  - *amount (total g) of carbohydrate consumed post shift (to maximize glycogen resynthesis)*
  - *liquid carbohydrate consumption patterns during the day.*
- Document level of oxidative stress that may have existed in the subjects from TEE/Energy Balance studies (wildland firefighters and normally active controls). This would require further analysis of existing samples for the following:
  - *urinary levels of ketones (protein catabolism, elevated rates of gluconeogenesis)*
  - *3 methylhistidine (protein catabolism)*
  - *malondialdehyde (marker of oxidative stress)*
- Assessment of upper respiratory distress in the fire camps (percent visits to the medical tents, evaluate working conditions such as shift length, temperature, caterer meals provided) in a quantitative/qualitative study to determine "trends" in upper respiratory infections/complaints.
- Development of a nutritional issues/ energy expenditure guidelines brochure and/or video.

  It would be beneficial to work with a sports nutrition expert to develop an example menu (using typical caterer menus) that would provide a set number of kilocalories per day. The brochure could be used to stress the importance of liquid carbohydrate intake during the shift and carbohydrate ingestion after the shift. It could also include typical work-related tasks and projected rates of energy expenditure to give wildland firefighters a sense of what they should eat to maintain energy and proper nutrition.
- A controlled study of smokejumpers during preseason training.

  Use the controlled preseason period for a study of energy balance, dietary intake, immune function measures, and oxidative stress.
- Performance-related studies:
  - The maintenance of blood glucose and immune function during field operations using energy bars (solid) and carbohydrate beverages (liquid).

- Effects of solid/liquid carbohydrate feedings on self-selected work rates.
- Effects of solid/liquid carbohydrate feedings on cognitive function in the wildland firefighter.
- Monitor profile of mood states survey for changes during acute and seasonal wildfire suppression activity.

- Field trials:
  - *Field acceptance of solid/liquid carbohydrate sources.*
  - *Field acceptance of modified meals.*
  - *Changes in eating behavior related to educational materials.*

Individual Factors

Fire and the environment are not biased; individuals should be eligible to be a wildland firefighter if they meet the requirements of the job and perform as required.

Recommendations

Fitness and wellness should be practiced all year long, not just during the fire season.

- Develop and assign Fitness Coordinators on each unit
- Provide preseason fitness training information
- Develop a multimedia fitness training package
- Encourage physical training time for all red-carded personnel
- Provide medical screening for all fire personnel before the season
- Encourage continuous support of agency Wellness programs.

Implement the Work Capacity Tests in all Agencies–*Immediately*–The Pack Test is appropriate if test candidates are adequately prepared and the test is administered according to the instructions.

Communication is Essential to Ensure Proper Dissemination of Information–

- Assure that information is disseminated by multimedia efforts
- Information needs to be consistent across agencies.

Improve Outreach and Recruitment of Wildland Fire Personnel

- Hire the best qualified individuals for fire positions
- Develop an interagency multimedia outreach and recruitment program
  - *Recognize and respect cultural traditions and beliefs in the fire organization*
  - *Include diversity outreach for attendance at national fire meetings.*

Firefighters are our most valuable asset, we have to treat them right and take care of them. Safety has to be the way we do business. All decisions must be made with safety in mind–at all levels of the organization.

Conference Papers

Director's Perspective

Jose Cruz, Director
Fire & Aviation Management
USDA Forest Service

I want to thank Dr. Brian Sharkey, Dick Mangan from MTDC and the NWCG Safety and Health Working Team for putting this Conference together. They have assembled some of the best technical experts on safety issues affecting the wildland firefighting community. The success of the conference will depend, in part, on us participating and sharing our thoughts on the issues presented. I encourage you to voice your opinion through frank, honest discussion.

We have numerous agencies at the local, State, and federal level attending. This level of participation, with a variety of specialists, promises to be the type of conference we can all learn from. Thanks for being here and for your commitment to the professionalism of our wildland fire program.

I was asked to give a director's perspective on the wildland fire health and safety issues. It's important that folks realize that my perspective is based on my experience, most of which is in the Western United States. So let me lay the framework of that perspective. My fire background includes:

- Hotshot
- Engines (foreman)
- Fire Organization background as
    - AFMO Assistant Fire Management Officer
    - FMO Fire Management Officer
    - FFMO Forest Fire Management Officer
    - Regional Fire Director
    - National Fire Director
- Line Experience
    - Ranger
    - Deputy Forest Supervisor
    - Forest Supervisor
    - Deputy Regional Forester
- I grew up under strong fire leadership of Dick Millar, Gene Kemble, Lynn Biddison, Bill Cadola, Ken Clark, Woody Williams, Denny Bungarz, Larry Boggs, and Dave Anderson.
- I grew up where line officers Al West, Don Bauer, Mike Edrington, and Mike Rodgers were fully connected to fire.
- I grew up where training manuals were a key part of our education and that have formed some of the training of current courses. I grew up where we had some of the best available equipment. I grew up where we learned basic business and management principles. I grew up where safety was a constant reminder and integrated with all aspects of our work.

So with this background, I believe that safety must be our number one priority as we conduct our business. There is nothing in the wildland we protect that should cause us to risk people's lives. If we follow our safety guides, the risk to our employees will be minimized. Additionally, I believe the environmental factors that affect our employees must be examined so we can provide safety equipment or ensure firefighters get the proper rest and their other needs are met. We must prepare our employees to deal with first responder responsibilities, ensuring they have training to avoid bloodborne diseases or other more hazardous situations.

I am pleased to be part of the conference and am looking forward to hearing the presentations and seeing the recommendations from the conference. I am looking forward to the proceedings publications. These will allow others who were not able to attend to have access to our discussions and recommendations.

It was not long ago when a conference presented by one of the Technology and Development Centers focused on equipment, tools, and other things related to our work. The interest in the human aspects of our work has been given greater emphasis, bringing us to focus on the safety and health of our fire folks. This conference is critical for the wildland fire community as we work to keep employees out of harm's way. Providing employees a safe work environment is critical to our success.

Over the last 4 to 5 years, our agency has placed a great deal of emphasis on safety. In *Course To The Future, Positioning Fire and Aviation Management,* then Chief Jack Ward Thomas sent one of the strongest messages I have received in my career. He wrote, "Safety is both a personal and a Forest Service responsibility. I am, therefore, demanding your personal involvement and commitment in leading our workforce to reestablish the highest regard to our safety program."

Other planning and strategic documents such as the Federal Wildland Federal Policy and Program Review emphasize safety as top priority. The IMRT (Interagency Management Review Team) report went further, stating: "The direction and tone that senior management sets is critical for making long-term institutional changes. Personnel at all levels must be held accountable for their actions."

"Current direction to streamline, downsize, reconfigure, and otherwise change organizations to meet budgetary constraints have the potential to severely affect firefighter safety."

The Wildland Firefighter Safety Awareness study recommended:

> ***.... Changing the organizational culture as it relates to wildland firefighters' safety will require commitment at every organizational level....***
>
> ***.... Changing the way business is conducted requires people at all levels to lead by personal example in demonstrating new approaches to achieve safer operations.....***

The report recommends that safety become a core value of the fire organization.

These are the values that make us what we are as individuals and as an organization. Having people like me standing up here talking doesn't make it happen. I can and will do my part, which is to believe in these core values, provide leadership, communicate my expectations, create a management environment that supports and encourages safe behavior, and hold people accountable.

To make this change happen we each must be part of the team that speaks with one voice, takes responsibility, does what is right, and makes doing things safely a natural part of our behavior, whether on the job or off.

We must have zero tolerance for unsafe behavior and must hold ourselves and others accountable for safety. Safety must be totally integrated in our thought processes and actions.

This conference is critical and very timely for the wildland fire community as we work to implement our highest priority—providing for the safety of our employees. Forest Service Fire and Aviation Management has formalized a statement of **Core Values.** They are **Safety**, **Integrity**, and **Mutual** respect. We've had these values for a long time, but the conscious act of formally writing them and communicating them gives us focus and provides a constant reminder so we do not forget or overlook them in the heat of battle.

The very theme of this conference leads to fulfilling the core value of safety for our people. It seems the human element of safety is far more challenging than the aspects dealing with equipment, procedures, and training. Humans are more complex, more variable from one to another. As I studied the program for the conference, I could not help but be impressed by the variety of topics to be presented and discussed this week as by well as their interconnectedness. Integrating them is going to be a challenge for all of us.

It is appropriate that we are participating in a workshop hosted by the Missoula Technology Development Center here today. Since the 1960's, MTDC has worked to improve the health and safety of wildland firefighters. A few highlights of the Center's efforts include:

1960's—MTDC began developing a test for firefighters to address the unacceptable health-related fatality rate experienced on fire assignments. Studies were also conducted on tools, fire clothing, and work practices.

1970's—MTDC released the Step Test that was adopted by all federal wildland fire agencies and many States as part of the wildland fire qualifications system. Work was begun on studies of heat stress, the effects of firefighter exposure to carbon monoxide, and work/rest cycles.

1980's—MTDC developed a wellness program model, a new handtool (the combi tool), and conducted tests on firefighter dehydration/hydration and work clothing.

1990's—MTDC released the family of Job-Related Work Capacity Tests (Pack, Field, and Walk Tests) and concluded the study of the health effects of wildland fire smoke on firefighters.

Clearly, MTDC has a history of studying and publishing information and solutions to real-world problems for the fire community. I am sure all of us here today has publications, videotapes, and other MTDC products in our offices.

I have confidence this will be a landmark conference. I want to challenge you—us as professional fire people—to listen well, get involved with the conference process, and apply the results of the labor of the presenters. It is we who make a difference. Our highest priority is taking care of our people. The goal is right; the time is right. This is the time; this is the place; and we are the people. Let's make a difference! Have a productive conference.

Defining Fire And Aviation Safety And Health Issues

Dave Aldrich
USDA Forest Service
National Interagency Fire Center

The wildland fire management community has spent a lot of time during the last 5 years talking about and describing our culture in terms of safety and health. We've looked at how we value and do not value safety, how our safety values change depending on what we are doing at the time, and most importantly, identifying how we can change our culture to consistently ensure the safety and health of wildland fire personnel. The Forest Service has adopted a goal that gives us direction and a measurable performance criterion for safety. The Goal is **Zero Accidents**. The goal includes occupational illnesses in addition to the traditional accidents. The message is clear. We are to plan and conduct our fire program activities so there are no accidents or occupational illnesses. A goal of any other number says we accept planning and conducting activities with the expectation that someone is going to be injured or suffer occupational illness as a result of the work. I think the goal of zero accidents provides a meaningful context to define fire program safety and health issues and to develop measures to resolve the issues.

We must recognize that fire program activities occur in an environment with inherent risks—environmental risks and risks of our own making. Some of the risks are relatively static and others are dynamic. The work of fire management is arduous. It is hard, dirty work in a hostile environment. It often lasts days, weeks, and even months. The critical human element is highly variable. Now to this, add some cultural realities. Our fire program workload is expanding in terms of the amount of work to be done. The revised fire policy challenges us to take a more professional approach to fires. Accomplishing the expanding fuels job will be a challenge. Our work is becoming more complex with expanding interface and fire-use programs. Fire programs are highly visible, resulting in high expectations with a lot of oversight and Monday morning quarterbacking. Our workforce has changed and will continue to change. We believe the numbers of people in the fire program pipeline and their skills will not be adequate to do the job ahead.

We, the fire program people, have a proud heritage of getting the job done. Nobody expects more of fire people than fire people. In spite of the popularity of this can-do attitude, it has serious safety ramifications that must be recognized and mitigated. We must put all of this in the context of our core value of safety and our goal of zero accidents and occupational illnesses. We must meet the goal! The other pressures and concerns must take their places in the priorities as they are compatible with the goal for safety.

This conference was designed to help us progress from general areas of concern through definition of specific and actionable issues to recommending ways to mitigate those issues. We will hear a lot of information from experts about many subjects during this conference. Later this week, we will break into small groups and define some safety and health issues and make recommendations for resolving them. In many cases the recommendations will resolve the issues. In some cases, the recommendations may be to do further research or to gather information.

Some of the areas I hope we can address this week include:

- What are the special requirements of work/rest cycles for wildland firefighters?
  - How long should our people perform arduous work during a day, during an assignment, or during a season?
  - How long should drivers drive without a break, during a day or during a given number of days?
  - What are the effects of nutrition on work/rest cycles?
  - What are the effects of wildland fire smoke and other environmental factors on work/rest cycles?
- What can we do to keep firefighters healthy, safe, and productive in the wildland fire environment?
- What are the effects of fitness and of appropriate work capacity on safety, health, productivity, and the duration of work assignments?
- What medical standards or requirements are needed for firefighter safety, health, and productivity? How do we implement them?

None of these is new—in fact, each item is a topic in the conference agenda. The task is formidable. There is extensive overlap and interaction between the issue areas and the applicable information. We have to be clear about what we are trying to accomplish and integrate the interrelated information into workable policies, standards, protocols, guides, contract specifications, and other management tools.

Beyond the technical challenge, we have others. Our work force has changed and will continue to change. It is a bit like wing shooting—we have to get out in front of the target or by the time our solutions arrive the target will be out of sight. We have new, nontraditional players involved in development of policies, standards, and other management products. They should be made part of the development process, not relegated to reviewers at the end. Every year there are new laws, regulations, and policies having profound effects on our work. We must hone our ability and inclination to work in an interagency and wildland-fire-wide mode. Finally, we have to remember we can't have different outcomes if we keep doing what we have been doing. We have to be willing to make our operations fit the standards—not try to adjust the standards to be compatible with the way we have historically done business.

The challenge for us is to listen well to our presenters, call on our collective experience banks and then with a keen eye on our goal of zero accidents, clearly define some crucial safety and health issues and develop some recommended resolutions.

Illness, Injuries, and Fatalities Among Wildland Firefighters

Richard J. Mangan
USDA Forest Service
Missoula Technology & Development Center

Wildland fire activities, whether they involve prescribed burning or wildfire suppression, take place in a high-risk environment. Persons involved in these activities, are at risk from illness and disease, injuries, and even death. In the years 1990 to 1998, 133 individuals died in activities associated with wildland fire.

This paper will discuss the environment that fire personnel work in, the kinds of hazards they are exposed to, and the types of illnesses, injuries, and fatalities that occur in the work force. In addition, workshop participants will be challenged to identify ways to reduce or eliminate adverse events that cause these illnesses, injuries, and fatalities.

The Work Environment

A wide variety of environmental and geographic conditions exist within the world of wildland fire. The wildland firefighter works in a wide variety of areas: from the Florida Everglades to the Alaskan tundra; from the high peaks of Glacier National Park to the Pine Barrens of New Jersey; from the Australian Bush to the West Texas hills. Environmental conditions in these areas include steep, uneven ground; high ambient air temperatures; elevations ranging from sea level to over 8,000 feet; and above-average levels of smoke and dust. All these conditions have the potential to affect the performance of the wildland firefighter and may result in illness, injury, or death. These factors, especially for individuals not acclimated to them, can have a cumulative effect on a firefighter's ability to resist them.

The Firefighter Work Force

The individuals that participate in wildland fire operations are as varied as the terrain and fuel types that they work in: they include females and males of all racial backgrounds; they must be at least 18 years old but often are in their 50's; and 60's; sometimes they weigh less than 100 pounds or more than 250 pounds; they may be from under 5 feet tall to over 6 feet 6 inches tall. Although they must meet the physical fitness requirements of their agencies, they often come to the wildland fire environment with the same physical conditions as the general population: allergies to smoke and dust, bad backs, and trick knees. They may be out of shape and have other preexisting conditions that may surface on the fireline.

The Firefighting Job

In addition to the environmental and human factors already described, the other critical factor that contributes to wildland firefighter illnesses, injuries, and deaths is the job itself. Long hours of arduous work under difficult physical conditions, coupled with reduced sleep and dietary changes, plus exposure to a new group of individuals who may have the potential to spread infections, all during a period of reduced immunity: these are prime conditions for illness or injury to strike the firefighter, especially on a prolonged fire assignment.

Firefighter Illnesses

The illnesses reported by wildland firefighters are not very different from those suffered by other large groups of individuals thrown together in a close environment for extended periods of time–such as sailors at sea, or teachers and students in a classroom. The introduction of endemic levels of infection and disease in any one individual has the potential to cause visible signs of illness among other individuals who have not had previous exposures and the opportunity to develop an immune response. Wildfires not only bring a large group of people together, they complicate the equation by requiring long hours of hard work, coupled with a change in diet and sleep patterns. These factors, and the exposure to smoke and dust, result in a variety of illnesses, especially as the duration of a fire assignment progresses beyond the first week.

The effects of long-term exposure to high levels of environmental smoke from wildfires was most apparent in the 1987 and 1988 fire seasons. In those years, smoke inversions plagued not only the immediate fire area, but also the incident base camps and surrounding communities for days on end. For firefighters spending multiple 21-day assignments under those conditions, the incidence of upper respiratory tract infections was widespread and lasted for as long as 3 to 4 months after the fire operations were over. As a result, the Health Hazards of Smoke project sponsored by the National Wildfire Coordinating Group (NWCG) was undertaken at the Missoula Technology and Development Center (MTDC). The 6-year project culminated in 1997 with a Consensus Conference in Missoula, Montana, that summarized the research findings and developed mitigation measures to reduce exposure to smoke during on-the-ground fire operations.

The long fire season in northern Idaho and western Montana during 1994 offered another opportunity to look at the incidence of illness among firefighters on large fire incidents managed by fire overhead teams. An informal review of medical records conducted by Mark Vore from the Idaho Panhandle National Forests showed that nearly 40% of the visits to the Incident Medical Units were documented as respiratory problems. These findings are consistent with the problems that surfaced in 1987 and 1988. Respiratory problems could arise in future fire seasons, given the mountainous terrain and inversion potential that exist on many large wildfires and prescribed burns in the Western United States.

Another illness that appears to be more common during wildfire operations is heat stress. Under conditions of both high ambient air temperatures and high radiant heat flux, the firefighter can easily become dehydrated and even become a heat stress casualty if positive preventative measures are not implemented daily. A recently completed Australian study on work productivity among bushfire fighters indicated that personal protective clothing was a key factor in reducing heat stress. Project “Aquarius” noted that two-thirds of the firefighter’s heat load was generated internally, with only one-third coming from the radiant heat of the fire. They recommended that the design of protective clothing should be to “let heat out, not keep heat out.” Additionally, they recommend that wildland firefighters working in high temperatures with a heavy workload consume as much as 1 liter of fluids per hour. The logistics of supporting this level of fluid replacement during a 12-hour operational period can be challenging, but the fluids are essential to prevent heat stress illness. Dehydration and heat stress illness can be the result of a progressive deterioration that occurs over several days of reduced fluid intake, and can be compounded by other factors such as other illnesses or medications.

Firefighter Injuries

Injuries are one of the major perils wildland firefighters are subject to. Although no documented records show trends of firefighter injuries, on-the-ground observations by experienced personnel show several major areas where injuries occur:

- Vehicle accidents
- Tool use
- Slips/trips/falls
- Muscle strains.

Several of these injury areas can be related to the casual factors of fitness level and fatigue. As firefighters become more fatigued from long hours of arduous work, they become less attentive to the small things that prevent injuries under different circumstances:

- Using care when walking on steep slopes, over logs, down cut slopes.
- Clearing obstacles and using full muscle control when swinging hand tools.

- Using proper lifting techniques for heavy objects.
- Keeping full attention on safe driving techniques when driving on windy, steep, unsurfaced roads.

Better documentation showing the rate of occurrence of these accidents on fire operations will more clearly define the problems and lead to practices that can mitigate the causes of these accidents and reduce their occurrence. The MTDC publication, "*Fitness and Work Capacity*" (9751-2814-MTDC), documents many of the conditioning techniques that can reduce firefighter fatigue by increasing work stamina.

Firefighter Fatalities

Two major wildfire fatality events occurred in the United States during the early 1990's: the Dude Fire in 1990 killed 6 firefighters; 14 firefighters died on the South Canyon Fire in 1994. Although these tragic events were reminders of the risks inherent with wildfire suppression activities, they represent just a portion of the total deaths that occurred from 1990 to 1998. During those years, 133 firefighters and others involved in wildfire operations died from a variety of causes. A recent MTDC Technical Report, "*Wildland Fire Fatalities in the United States*" (9951-2808-MTDC), documents those causes, including aircraft accidents (30 deaths), heart attacks (28 deaths), and vehicle accidents (25 deaths).

Numerous opportunities exist to reduce firefighter fatalities off the immediate fire ground, through many of the same actions that will reduce illness and injuries. Reducing deaths from heart attacks offers the best opportunity to cut the number of firefighter fatalities. A major lifestyle change will be required to reduce the risk of heart attack for many firefighters.

Challenges to the Conference

As we begin this conference on the Health and Safety of Wildland Firefighters, we have the opportunity to help set the course of action for studying these issues during the upcoming 5-year period of work. The following items would be desirable outputs from this conference:

- Identify the medical screening needs for incoming and returning personnel involved in wildland fire operations.
- Define the special nutritional needs for performing arduous work for extended periods of time.
- Specify length-of-shift and length-of-assignment periods for multi-period wildfire incidents, as well as prolonged prescribed burning operations, or the combination of the two types of operations.
- Recommend enhancements to existing fitness and wellness programs to improve firefighter performance while reducing illness, injuries, and fatalities.
- Consider improvements to the work capacity testing process to identify special performance needs for specific positions in the fire organization.

This conference offers the wildfire community, in the United States and around the world, an opportunity to make significant gains in the safety and well-being of our firefighters. The challenge is yours to use all of your collective wisdom and experience to not only better define the problems but to offer innovative and far-reaching solutions for the twenty-first century.

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Demands of the Job

The Development and Validation of a Job-Related Work Capacity Test for Wildland Firefighting

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"That a man must be physically sound for his work we know, but a standard of soundness has never been defined . . it is urgent that a simple but effective method be used by all employing officers to insure the rejection of the clearly unfit."

Coert Dubois, USDA Forest Service, Southwestern Region (R5), 1914

This paper reviews the determination of job demands and the development and validation of a job-related work capacity test for wildland firefighting. It will also identify other job-related issues that may impact the health and safety of wildland firefighters.

Background

In 1965 The Missoula Equipment Development Center (now the Missoula Technology and Development Center), and cooperators from the University of Montana Human Performance Laboratory began work on a test to determine a candidate's fitness to perform arduous wildland firefighting tasks. Field measurements of the metabolic, cardiovascular, and thermal demands of firefighting tasks were made on firefighters working on controlled (prescribed) burns. The results indicated that wildland firefighting tasks fell into the category of hard work, with average energy expenditures of 7.5 kcal/min. Based on these measurements and a review of the literature, it was concluded that (for the firefighters then employed) aerobic fitness (max VO_2) was the primary limiting factor in the firefighters' ability to sustain hard work throughout long work shifts.

The Astrand-Rhyming Step Test was modified, validated, field tested, approved by the Civil Service Commission (now the Office of Personnel Management), and adopted in 1975 as the test to determine firefighter fitness for duty. Since workers cannot sustain day-long workloads above 50% of their maximum capacity, the average energy cost of firefighting duties (22.5 ml/kg.min) was doubled to determine the minimum score (45 ml/kg.min) for wildland firefighters. Soon after the test procedure was implemented, concerns arose that some workers lacked the muscular strength to do the job. These concerns coincided with the integration of women into the wildland firefighting workforce. Field studies of muscular fitness and work capacity (Sharkey, Jukkala, Putnam, and Tietz 1980) confirmed the relationship of strength and lean body weight to performance in firefighting (the average female has 50 to 60% of the upper body strength of male workers). Recommendations to add muscular fitness measures to the selection process were not adopted. The Step Test (and alternative 1.5-mile run) remained the measures used in the selection of firefighters.

In 1994 MTDC was assigned to review test procedures and revise training materials to ensure compliance with new laws, regulations, and recent research. MTDC conducted an extensive review of the scientific literature and legal precedents related to employee selection, and surveyed field comments to determine worker satisfaction with the existing tests. Research, new laws, and field responses all called for revision of the fitness tests. The Step Test violated the American's with Disabilities Act (use of biomedical data; specifically the heart rate: Equal Employment Opportunity Commission EEOC #915.002, 5/94), the test was not directly job related, and there was evidence of cheating (use of drugs to lower the heart rate). Workers were dissatisfied with the test and eager for a change. MTDC undertook a revision of the wildland firefighter Job Task Analysis, and then conducted a series of laboratory and field studies on the development and validation of a job-related work capacity test.

Job Task Analysis

The Job Task Analysis was conducted with input from National Wildfire Coordinating Group (NWCG) member agencies and some States. Respondents rated the importance as well as the intensity, duration, and frequency of tasks. New categories in the revised analysis included:

- Performing under adverse conditions (including long work shifts; rough steep terrain; heat, cold, altitude, and smoke; insufficient food, fluid replacement, and sleep)
- Emergency responses (fast pull-out to safety zone, rescue or evacuation assistance to others).

The analysis indicated that the most important firefighting tasks included:

- Building fireline with handtools
- Performing under adverse conditions
- Hiking with light loads
- Lifting and carrying light loads.

Tasks receiving lower ratings, primarily because they occurred less frequently included:

- Packing heavy loads
- Emergency responses
- Using chain saws.

Wildland firefighting clearly deserves the definition of arduous work:

> ***"Duties involve field work requiring physical performance calling for above-average endurance and superior conditioning. These duties may include an occasional demand for extraordinarily strenuous activities in emergencies under adverse environmental conditions and over extended periods of time. Requirements include running, walking, climbing, jumping, twisting, bending, and lifting more than 50 pounds; the pace of work typically is set by the emergency condition." (NWCG 310.1)***

Job-Related Work Capacity Tests

The test development and validation process followed the *Federal Uniform Guidelines for Employee Selection Procedures.* MTDC used the job task analysis and data from past field studies to identify potential tests. Based on high correlation to other firefighting tasks, a fireline construction (Pulaski Test, upper body) and a load carry (Pack Test, lower body) were the tests best correlated with performance. They were selected for further laboratory and field evaluation.

Laboratory Studies

The Fireline Test and Pack Test were found to have energy costs similar to those required on the job (7.5 kcal/min). Both tests were significantly correlated to laboratory measures of aerobic and muscular fitness, and to performance on firefighting tasks. And both were judged to be valid, reliable, objective, and job-related measures of work capacity. However, because of its reliance on upper body strength, the Fireline Test was found to have adverse impact on females (based on the EEOC 80% rule; females passed at less than 80% of the males' pass rate). Moreover, the Fireline Test requires a higher administrative cost (test equipment, time). The Pack Test uses available equipment and does not show evidence of adverse impact. The flat version of the test is highly related to performance on a hilly course ($r = 0.87$, although the hilly course had an adverse impact on female candidates). A score of 45 minutes on the Pack Test approximates a score of 45 on the Step Test (the current standard for wildland firefighters). Based on these studies (Sharkey, Rothwell, and DeLorenzo-Green 1994; DeLorenzo-Green and Sharkey 1995) the Pack Test was scheduled for field trials.

Pack Test Field Trials

During the 1995 fire season, field trials were conducted on 320 firefighters from three regions of the Forest Service, three federal agencies, and one State. The sample represented the gender and ethnic distribution of the firefighter population (Sharkey, Rothwell, and Jukkala 1996). Ethnicity did not appear to be a factor in test performance. For a passing score of 45 minutes, males passed at the rate of 84.4% vs 71.9% for females. Thus females passed at 85.2% of the male pass rate, which does not constitute adverse impact as defined by the EEOC. The field trial was not a condition of hire, so some subjects did not give their best effort. Also, field experience has shown that subjects improve substantially when retested, so those within 1 minute of the passing score would be likely to pass on a retest (89.5% of the males and 79.7% of the females were under 46 minutes, yielding a female/male pass rate of 89%). The scores were also analyzed for the effects of age, height, and weight.

Age

Subjects ranged from 18 to 63 years old, and included 30 subjects over 40 years old. Those over 40 years averaged 41.4 minutes on the Pack Test, a score that was superior to the overall average (41.8 minutes). Of the 30 subjects over 40 years of age, 5 scored over 45 minutes and 25 under 45 minutes, for a pass rate of 83.3%. This pass rate exceeds the pass rate for all subjects (81.9%).

Height

Heights ranged from 61 to 79 inches with an average of 69.7 inches for all subjects (70.6 inches for males and 66.3 inches for females). While the data for all subjects suggested a relationship between height and performance on the Pack Test ($r = -0.294$), analysis of scores above 45 minutes revealed no significant relationship ($r = -0.022$. $r^2 = 0.0005$). The correlation squared (r^2) indicates the proportion of the variance in performance accounted for by a relationship. Far less than 1% (0.05%) of the variation in performance among test scores over 45 minutes can be attributed to height.

A 1998 field evaluation of over 5,000 firefighters verified the results of the 1996 field trial. However, it identified a somewhat lower pass rate for 101 individuals under 5 feet 3 inches in height. Subsequent analysis of the 33 who did not pass indicated that 18 did not finish, 10 were overweight, several were underweight, 9 did no training, and 27 completed less than 12 hours of training for the test. The results suggested that those factors and the low lean body weight associated with short stature contributed to the somewhat lower pass rate.

Weight

Weights ranged from 104 to 270 pounds, and averaged 170.9 pounds for all subjects (178.7 pounds for males, and 140.9 pounds for females). There was no relationship between weight and performance on the Pack Test for all subjects, by gender, or for those who scored over 45 minutes.

Pack Test Summary and Recommendations

The Pack Test is a valid, job-related test of work capacity. The test uses a firefighting tool (pack) and requires an energy cost similar to that demanded on the job. Pack Test scores are correlated to laboratory measures of fitness, and to performance of the

firefighting tasks identified in the job task analysis. The duration of the test ensures the capacity to perform prolonged arduous work, under adverse conditions, with a reserve to carry out emergency responses. Pack Test scores are not adversely influenced by gender, ethnicity, age, height, or weight.

Recommendations

- Introduce the Pack Test in a national interagency implementation program during the 1996 fire season. (delayed until 1998)
- Pack Test becomes a Red Card requirement in 1997 (retire Step Test and 1.5 mile run). (delayed until 1998)
- Develop field (hiking) tests for other fire-related jobs (moderate and light work categories). (accomplished in 1996)
- Develop materials to support the test battery including:

Fitness and Work Capacity—a revision of a 1977 publication dealing with fitness, training, nutrition, the environment, testing, etc. (completed 1997)
Work Capacity Tests for Wildland Firefighters—the Test Administrator's Guide. (completed 1998)
Fit to Work—a brochure to help firefighters prepare for the test and the job. (completed 1998)
These materials are available from the National Fire Equipment System.

Testing and Training

Health Screening
The American Heart Association (AHA) and the American College of Sports Medicine (ACSM) recommend a medical examination for persons over 45 years old, for those with heart disease risk factors, and for individuals who have been sedentary before a major increase in activity. For many others, a simple health screening questionnaire provides assurance of the readiness to engage in training, work, or a job-related work capacity test.

PAR-Q
Par-Q is a health screening questionnaire designed to identify that small number of individuals who should seek medical advice concerning involvement in moderate activity (exercise intense enough to result in fatigue within 20 minutes). A "no" answer to seven simple health questions indicates suitability for involvement in an exercise test or moderately vigorous aerobic and muscular fitness training. The revised PAR-Q questionnaire was developed and validated by the Canadian Society for Exercise Physiology. Use of the questionnaire substantially reduces the risk of taking exercise tests or training for apparently healthy adults. Candidates for fitness training, firefighting, and field work should complete PAR-Q screening before taking a work capacity test or beginning strenuous training. An alternative one page screening form may be found in the 1998 AHA/ACSM recommendation. The recommendation raises the age for more intensive screening from 40 to 45 years old.

Persons Over 45 Years Old
A physician may recommend an electrocardiogram-monitored exercise test for individuals over 45 years old, with one or more heart disease risk factors (such as smoking, high blood pressure, or elevated cholesterol), for those who have been inactive, or for those whom the test, training, or work represent a significant increase in exercise intensity.

Medical Examinations
Wildland Firefighter Health and Safety Conference participants discussed the need for more extensive health screening, physician examinations, and medical tests for wildland firefighters. Federal agencies are currently considering a comprehensive medical history, medical tests, and physician examination for entry-level firefighters. The medical history would be updated annually, and the physician examination and some medical tests would be repeated every 5 years under the current proposal. Costs include several hundred dollars per candidate for medical tests and physician examinations. Benefits could include early detection of health problems, some reduction in Occupational Workers Compensation Program costs, and assignment of candidates to more appropriate positions, when possible. Problems include the waste of scarce resources on a predominately young, generally healthy population, false positive results (indication of a problem that may not exist), and the costs of additional testing needed to clear candidates for work. Alternatives to comprehensive examinations include risk stratification by low-cost screening (such as the PAR-Q questionnaire) or a more comprehensive medical history, with tests and examinations for those at higher risk (for instance, those over 45 years old).

Training for the Pack Test

Before training, candidates should complete the PAR-Q questionnaire and see a physician if indicated. They should begin training at least 4 to 6 weeks before they report for duty. They can train by hiking or power walking, wearing the ankle-height footwear they will use during the test. Have candidates:

- Hike a 3-mile flat course without a pack. When they can cover the course in less than 45 minutes
- Add a pack with about 25 pounds for training hikes
- Increase the pack weight until candidates can hike 3 miles in 45 minutes with a 45-pound pack.
- Also:
    - Hike hills (with a pack) to build leg strength and endurance
    - Jog the flat course (without a pack) to build aerobic fitness
    - Cross-train (ride a mountain bike, lift weights) to build stamina and strength.

Job-Related Issues

Other job-related issues considered at the Wildland Firefighter Health and Safety Conference included:

- Seasonal work/exposure limits
- The 21-day assignment
- Shift length.

With the increased use of firefighters for spring- and fall-burning programs, and the increasing severity and duration of fire seasons, seasonal exposure limits may have to be considered. Conference participants also considered alternatives to the 21-day assignment. In addition to issues of fatigue, nutrition, rest, and health (immune system), participants considered the effect of assignment or shift length changes on firefighter compensation. Suggested changes can be found in the Recommendations section of this publication.

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De-Lorenzo-Green, T.; Sharkey, B. Development and Validation of a Work Capacity Test for Wildland Firefighters. Medicine and Science in Sport and Exercise, 1995.

This study investigated alternative work capacity tests based on a comprehensive job analysis that identified tasks requiring strength and endurance of the legs and upper body. Eight male and 7 female volunteers performed direct (treadmill) and indirect (step test) tests of maximal oxygen intake; muscular fitness tests (bench press, pull down, push up); a field Pack Test (PT) consisting of a 4.83 km (3 mile) hike over level terrain while wearing a 20.5 kg (45 lb) pack (performed w & w/o a respirator); and a five minute simulated fireline construction test (FT). Subjects also performed pack and line building trials to determine the energy cost of each activity. Results indicated that the energy cost of the PT at 4 mph was 22.2 ml/kg-min, which is similar to the documented cost of firefighting duties, including line construction (22 ml/kg-min). There was no significant difference between males and females on the PT, but there were differences between males and females on the FT (161 vs 109 ft; $P < .013$) and the muscular fitness tests ($P < .0001$). There was no significant difference in PT performance with or w/o a respirator, and the trials were highly related ($r = .92$) indicating test reliability. The PT performance was correlated to the FT (-.79) and pull down (-.72). The FT was correlated to the pull down (.73), the push up (.70), and VO_2 max (.56). Results indicate that the PT and the FT are valid and job related, but the PT has lower administrative costs and less potential for adverse impact.

Department of Labor, Uniform Guidelines for Employee Selection. Federal Register, Aug. 25, 1979.

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Sharkey, B.; Rothwell, T.; DeLorenzo-Green, T. Development of a Job-Related Work Capacity Test for Wildland Firefighters. Medicine and Science in Sport and Exercise, 1994.

Since 1975 Federal land management agencies have used a 5-minute step test to select wildland firefighters. New laws (ADA), field experience, and research concerning long-term work capacity have led to a re-examination of the selection procedure. This study is the initial step in the search for a new test. Eighteen volunteers (9 male, 9 female; 20-36 years old) performed direct and predicted leg tests of maximal oxygen intake, arm tests of peak VO_2 and sustained (30 min) performance, a battery of muscular fitness tests, and a field (pack) test which consisted of a 4.83 km (3 mile) hike over level terrain while wearing a 20.5 (45 lb) pack. Blood lactate measures were recorded after each test. The analysis was intended to determine the relationship of the candidate (Pack) test to the existing test, and to identify factors correlated with the Pack Test. Results showed significant differences in muscular fitness measures between males and females, but neither leg VO_2 max nor Pack Test differences were significant (49.4 - 43.4 ml/kg-min; P = .085; and 40.1 - 44.9 min; P = .059 respectively). The Pack Test was significantly related to the step test (r = -.455) and the leg VO_2 max (-.579), and to muscular fitness measures, including leg press (-.553) and pull-ups (-.501). The Pack Test also correlated to arm peak VO_2 (-.52), the arm VT (-.592), and the sustained arm endurance test (-.707). Multiple regression analysis of Pack Test performance vs. aerobic (arm and leg VO_2 max, arm endurance, Pack Test lactate) and muscular (leg press, pull-ups) yielded R = .846. The results indicate that performance on the Pack Test involves components of aerobic and muscular fitness, and that a time of 45 minutes for the 3 mile test approximates the current fitness requirement of 45 ml/kg-min.

Sharkey, B.; Rothwell, T.; Jukkala, A. Validation and Field Evaluation of a Work Capacity Test for Wildland Firefighters, Medicine and Science in Sport and Exercise, 1996.

This is the final phase in the development of a job-related work capacity test for wildland firefighters. This study related the candidate Pack Test to field performance and measures of aerobic and muscular fitness, and evaluated the potential for adverse impact. Ten male and 10 female volunteers (ages 21 - 40) performed strength and VO_2 max tests, 4.83 km (3 mile) hikes with a 20.5 kg (45 lb) pack (PT) on both a level and a hill course (w 0.23 miles @ +17.5%), and a 15 min simulated fireline construction test (with handtool). Males and females did not differ significantly on the PT (39.2 vs 42.4 min respectively). Times for the flat and hill versions of the PT for males and combined (male/female) subjects were not significantly different, but were for females (dif = 2.56 min, p < .01). The flat and hill versions of the test were significantly related (r = .87). They were correlated to strength measures (pull-up, r = -.61 & .67; push-up = -.68 & .67), VO_2 max (r = -.77 & .65), and the fireline test (r = -.50 & -.60) for flat and hill tests respectively. The results confirm the relationship of the PT to field performance (hill course, fireline test), and to measures of strength and aerobic fitness. Regression analysis indicated that a score of 45 min for the 3 mile Pack Test approximates a VO_2 max of 45 ml/kg-min, the current standard. A field evaluation of 320 incumbent firefighters (69 females) did not reveal evidence of adverse impact.

Energy Expenditure and Energy Intake During Wildfire Suppression in Male and Female Firefighters

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Introduction

Historically, wildland firefighters have been required to pass an aerobic fitness test (minimum score of 45 ml/kg-min) before employment. They undergo strenuous physical training before the fire season. Forest fire suppression involves arduous work (average = 7.5 kcal/min) for prolonged periods (12 to 24 hours) in difficult environmental conditions (heat, altitude), including exposure to smoke from forest fires (including respirable particulate, carbon monoxide, formaldehyde, acrolein, benzene from pumps, chain saws, and engines). A job task analysis identifies tasks such as packing heavy loads, building fireline with handtools, and emergency responses, often under arduous and dangerous field conditions. Firefighters perform their duties while wearing personal protective gear that balances the needs for protection, performance, and mobility. In busy fire seasons, firefighters may work as many as 21 days without relief, with meals provided by field rations, a remote fire camp, or an organized camp with full field kitchen. Even in the best camps, firefighters sleep on the ground in tents. When combined with pre- and post-season work on prescribed fires, firefighters may log over 100 days of work in a season and more than 1,000 hours in overtime. For these reasons, wildland firefighting simulates the stresses and strains of extended military operations. The job involves long hours of meaningful work that cannot be duplicated in controlled or make-work studies. Motivation to perform is maintained by a sense of mission and the pride of accomplishment. The fit and highly motivated women working on fire crews represent the capabilities of women who are willing to train to meet the demands of the job.

Because of the job hazards and the unpredictable nature of the job, measurements during the fire season are often difficult to obtain. Similarly, the use of laboratory equipment in the field is often impractical due to expense and the need for a controlled environment. Therefore, it is difficult to obtain samples and data collection from the wildland firefighter during situations of arduous wildfire suppression without affecting the “true” work environment. If the health and safety of the wildland firefighter is the number one concern, it is imperative that we have as much information as possible to establish sound policy regarding work-rest cycles and the nutritional demands associated with the occupation. With the use of the doubly labeled water methodology, day-long energy expenditure during wildfire suppression can be established.

The purpose of this investigation was two-fold:

- Determine the actual energy demands of 5 to 7 days of wildfire suppression in males and females using the doubly labeled water methodology
- Estimate energy intake patterns for assessment of dietary habits.

Methodology

Seventeen subjects (n=9 females, n=8 males) from three type 1 Interagency Hotshot crews were recruited as subjects for the investigation. The investigation was conducted during the 1997 and 1998 fire seasons and involved five different wildfires (CA, FL, WA, ID). Subjects were selected based on job tasks, gender distribution, and after consultation with the crew bosses, dependability. All subjects provided written consent prior to data collection with an Institutional Review Board-approved consent form. Before the fire season, subjects underwent descriptive measures of nude body weight (kg), height (cm), and body composition measures (skinfold Jackson and Pollock 1978; Jackson et al. 1980). Body density was converted to percent body fat using the age/gender-specific equations of Lohman (1992). Subjects were distributed into groups of similar total body weight to calculate isotopic delivery dose for the total energy expenditure measurement period. Subject's vials of ^2H_2O (99% APE) + $H_2{}^{18}O$ (8 and 10% APE) were mixed before the season to deliver a dose approximately equivalent to .14 g/kg body weight ^2H_2O and .250 g/kg body weight $H_2{}^{18}O$.

Deployment and Isotopic Delivery

The research team was deployed at the same time as the type 1 crew to reach the crew before wildfire suppression activity began. At each fire, a small number of subjects (three to five) were given the oral dose of doubly labeled water as mentioned above. The basic data collection protocol/timeline is outlined in Figure 1. Before isotopic dosing (at approximately 2200-2300),

each subject was allowed a normal dinner that was completed before 2000. After dinner, subjects were instructed not to consume additional foods until 0700 the following morning. A background urine sample was obtained from each subject immediately before isotopic delivery. Subjects consumed the isotopic solution in an approximate fluid volume of 160 to 180 mL. They continued drinking as the isotope container was rinsed three times with approximately 15 to 20 mL of distilled water to ensure complete consumption of the preweighed isotope. Subjects were instructed not to consume any additional water or food sources until additional samples were obtained the following morning. Any overnight voiding of fluid was collected and measured to correct the initially measured total body water. The following morning, the entire first void sample was collected and measured and a nude body weight was obtained. Within 60 minutes, a second void was also collected.

Daily urine samples were collected each morning (at 0400-0600) for the 5 to 7 day experimental period. Duplicate samples for each subject at each time point were placed into two separate tubes (Corning 4.5-mL cryogenic vials) and stored in a cooler. Following 5 to 7 days of wildfire suppression work, subjects were provided with a second dose of ^2H_2O (approximately 2.0 grams, 99% APE) in the evening to determine total body water at the end of the experiment. Following the collection of a background sample and the ^2H_2O dose, subjects were instructed to avoid food and beverage until the collection of first and second void urine samples the following morning. After the first void was collected, a nude body weight was obtained. Samples were analyzed for isotopic enrichments using an isotope ration mass spectrometer method as described by Schoeller et al. (1988).

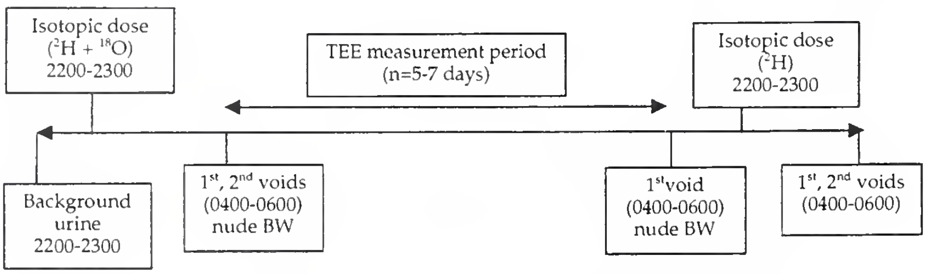

Figure 1—Total energy expenditure (TEE) protocol for isotopic delivery and sample collection.

Total water turnover rates were calculated from the established average total body water (based on a back extrapolation to the timing of the original dose), and the elimination rates of the ^2H and ^{18}O. Average daily CO_2 production was calculated from the isotopic elimination rates, the total body water and the rate of water turnover. The total CO_2 production (moles/day) was converted to Total Energy Expenditure (TEE, kcals/day) for the experimental period using an assumed food quotient (FQ) of 0.85 for each subject (volume CO_2 (1.1+3.9/FQ) • 22.4).

Dietary Record Analyses

Dietary intake during the seasonal measures was completed using a detailed food record/inventory of all ingested materials. When subjects were accessible in camp, tray surveys and measures of pre and post food weights were used. However, this was only possible for some dinner and breakfast times. Total intake patterns were assessed for carbohydrate, fats, and protein.

Results

The doubly labeled methodology allows the assessment of total energy expenditure (average kcals/24 hours for the entire study period) and the assessment of total body water. Table 1 shows the changes in nude body weight and body composition over the 5- to 7-day experimental period. It is important to note that the post body weight value has been normalized to adjust for changes in total body water.

Table 1—Changes in body weight, composition, and total tissue loss during the 5- to 7-day period of wildfire suppression using measures of total body water and skinfold.

Males	**Before Fire**	**After 5-7 Days†**
Body weight (kg)	75.8±7.0	75.4±7.0
Fat body mass(kg)	6.4±2.7	6.0±3.1
Fat-free mass (kg)	69.4±7.2	69.3±7.0
Females	**Before Fire**	**After 5-7 Days†**
Body weight (kg)	69.3±5.0	68.0±5.2*
Fat body mass(kg)	15.1±4.5	14.3±4.1*
Fat-free mass (kg)	54.1±4.0	53.7±3.0

† Post 5-7 day value is normalized to variations in total body water

* $p < 0.05$ that the difference in weight before the fire and after 5 to 7 days is due to chance.

Values of total energy expenditure are expressed in kcal/day and in kcal/kg body weight/day to normalize variations in expenditure due to total body weight. Table 2 shows the mean subject data for the male and female subjects. The TEE (kcal/24 hours) was significantly greater for males compared to females. However, when TEE was expressed relative to total body weight (kcal/kg/24 hours), there was no difference between males and females.

Table 2—Average estimates for total energy expenditure (TEE) during the 5- to-7 day period of wildfire suppression.

	TEE (kcal/24 hours)	**TEE(kcal/kg/24 hours)**
Males	4758±677	64.5±13.6
Females	3550±675*	55.0±10.8
Range	2872–6021	42.5–86.0

* $p < 0.05$ that the difference between males and females is due to chance.

Table 3—Reported dietary intake patterns during the 5- to 7-day period of wildfire suppression.

	Total intake	**% CHO**	**% fat**	**% protein**
Males	4068±939	47±6	36±8	16±3
Females	3222±712*	59±8	28±8	13±2

* $p < 0.05$ that the difference between males and females is due to chance.

Discussion

The calculated values for TEE measured during wildland fire suppression are similar to values previously measured during military operations (Table 4). The unique aspect of this study is the use of the doubly labeled methodology in an unpredictable "field" environment where conditions cannot be controlled. This subject population may serve as an ideal model to determine the effects of arduous occupational exposure on dietary adjustments during actual field operations. In addition, these data serve as a "minimal" or "average" standard for energy expenditure during work on the fireline.

Table 4—Measures of TEE using the doubly labeled water method during military operations.

Investigation	Activity	kcal/day
Hoyt et al. (1991)	Moderate cold/altitude, heavy exertion	4919±190
Jones et al. (1993)	Extreme cold, moderate exertion	4317±293
Hoyt et al. (1994)	Moderate cold/altitude, heavy exertion	4639±231

The doubly labeled water methodology also allows daily body water turnover rates (rH_2O) to be calculated. This allows water ingestion during a typical 24-hour period including the arduous physical and environmental conditions associated with the job to be precisely estimated. The average rH_2O for the subjects was about 8.0 liters/day (2.1 gallons or 8.5 quarts). These data further emphasize the hydration demands associated with arduous physical activity in the heat and indicate that water intake should be a priority among wildland firefighters during fire suppression. There are also concerns regarding how firefighters would be able to drink this much when it requires additional weight they must carry (2.1 gallons of water weighs 17.5 lb). Fresh drinking water should be available to ensure the hydration requirements of the job are met.

In reference to the dietary intake patterns, it is difficult to rely on "self-report" dietary intake records. Subjects often over and under report. After reviewing the total energy expenditure results, it appears that subjects were as accurate as possible given the unusual field conditions. Further research should be developed to understand the variety of dietary habits that persist among various crews (crew type, ethnic issues).

Although the males appeared to maintain a state of energy balance (maintenance of total body weight by matching energy expenditure with appropriate energy intake), the females did not maintain body weight (Table 1). However, the weight loss that did occur was the result of fat loss (a common occurrence associated with a typical aerobic exercise program designed to enable weight loss). What is troublesome are some of the eating attitudes that persist among crew members related to weight loss. Although our studies did not monitor common eating attitudes, it was alarming to hear anecdotal information regarding weight loss and the fire season. Several subjects stated that weight loss was common and that they typically used the first one or two fires of the season to "get in shape" for the main fire season. From a health and safety perspective, this practice should be discouraged. Figure 2 outlines the hazards associated with an inadequate diet (energy intake) and elevated occupational energy expenditure.

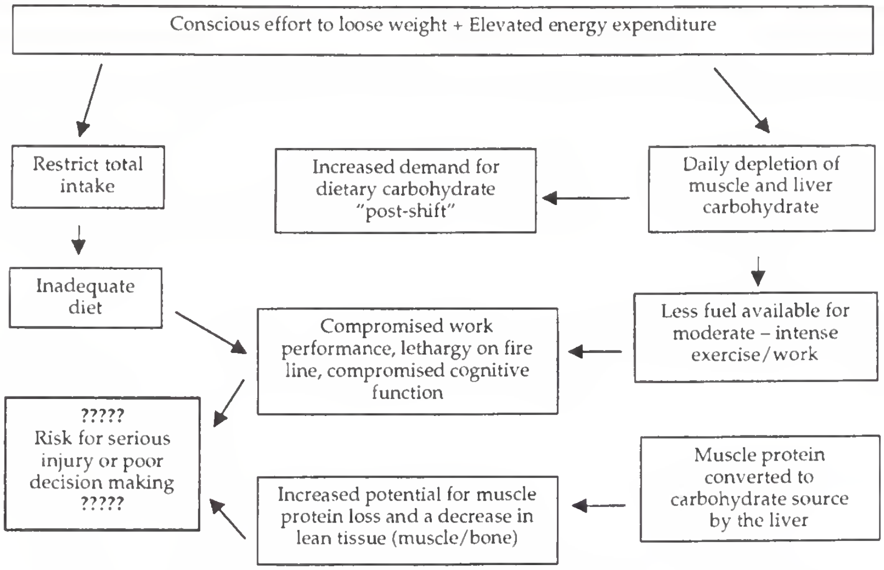

Figure 2—Schematic of the effects of negative energy balance on total body protein, cognitive function, and risk for injury.

Reasons for Concern and Projected Further Research

Several aspects of seasonal fire suppression and fireline work make them challenging from a dietary and energy balance perspective. The most apparent aspect is the unpredictable nature of the season that may lead to an abrupt persistent increase in total energy expenditure. It is difficult for most persons to suddenly increase their total intake to 4,000 to 6,000 kcal/day.

We are also uncertain whether the balance of carbohydrates, fats, and proteins are appropriate in the typical "caterer-supplied" diet. Although the caterers are held to a strict standard, the current standard has not been proven appropriate for the maintenance of muscle and liver stores of glycogen (carbohydrate). The wildland firefighter should be presented with the ability to ingest 250 to 500 grams of carbohydrate post shift in liquid and solid forms. If these are not readily available, the typical camp meal may not be restore muscle and liver carbohydrate levels before the next day's work.

It is also not known whether wildland firefighters are able to meet macronutrient needs associated with the elevated energy expenditure (and perhaps eating fatigue—a general loss of appetite due to extreme physical exertion), creating a state of negative energy balance. We do not know if the typical wildland firefighter needs a multivitamin supplement to ensure micronutrient needs (calcium, iron, B-vitamins). Typically, if the total energy expenditure is matched with a diverse energy intake, the micronutrient requirements are met. However, this requires further study with this unique population that works under adverse conditions.

Although it is unclear whether the dietary intake patterns and standards are optimal, it is clear that the energy demands of wildfire suppression are extreme. Further field research should be conducted in a similar environment investigating:

- The self-selection of food items in the fire camp
- Effects of energy balance on the maintenance of overall bone health
- Effects of energy balance on the maintenance of immune function.

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Acknowledgments
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Heat Stress

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Wildland firefighting is arduous work. Shifts are long, often in steep terrain and at higher elevations. The weather is usually hot and dry, and the fire increases exposure to heat. This report focuses on the risks of heat stress and what firefighters should do to minimize those risks.

When hard work is performed in a hot environment, blood is sent to the skin to cool the body, primarily through evaporation of sweat. As sweating continues, often at a rate of more than 1 liter per hour, the body loses a considerable quantity of fluid. Loss of fluid can compromise heart and circulatory function and the ability to work. If fluids are not replaced, the temperature-regulating process begins to fail, work becomes impossible, and the possibility of life-threatening heat stroke increases dramatically.

Heat Disorders

Heat stress disorders include heat cramps, heat exhaustion, and heat stroke.

- Heat cramps are involuntary muscle contractions caused by failure to replace fluids or electrolytes, such as sodium and potassium. Cramps can be relieved with stretching and replacement of fluids and electrolytes.
- Heat exhaustion is characterized by weakness, extreme fatigue, nausea, headaches, and a wet, clammy skin. Heat exhaustion is caused by inadequate fluid intake. It should be treated by resting in a cool environment and replacing fluids and electrolytes.
- Heat stroke is a medical emergency caused by failure of the body's heat controls. Sweating stops and the body temperature rises precipitously. Heat stroke is characterized by hot, dry skin, a body temperature above 105.8 ϒF (41 ϒC) mental confusion, loss of consciousness, convulsions, or even coma. While awaiting medical help, begin rapid cooling with ice or cold water, fanning the victim to promote evaporation. Treat for shock if necessary. For rapid cooling, partially submerge the victim's body in cool water.

Measuring Heat Stress

Figure 1 illustrates how temperature and humidity combine to create moderate or high heat stress conditions.

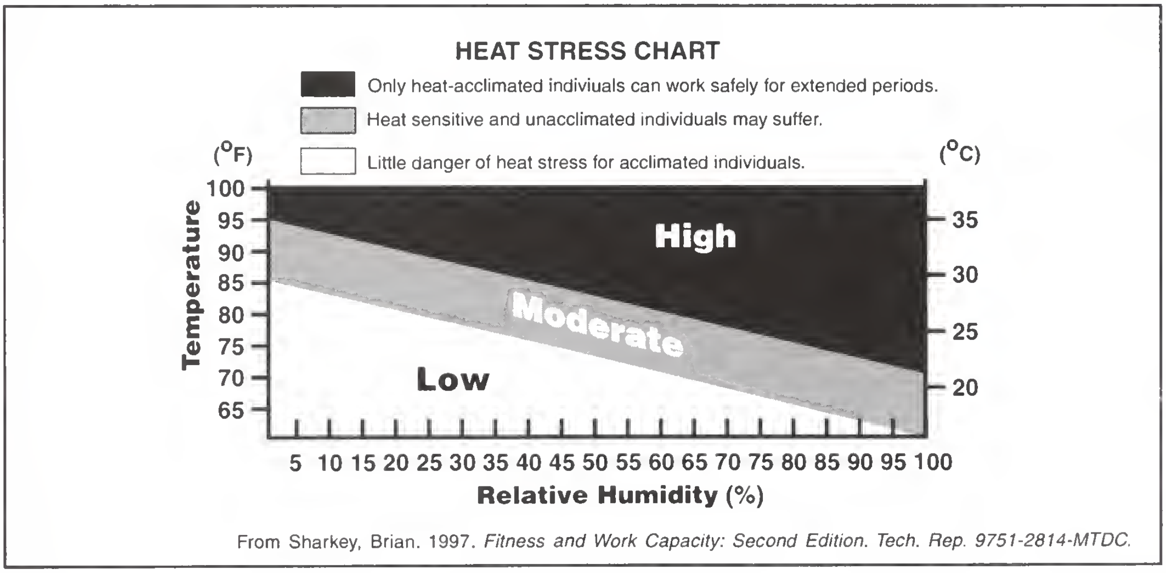

Figure 1—Heat stress chart.

The risk of heat stress increases when radiant heat from the sun or nearby flames is high, the air is still, or when someone is doing hard work and creating lots of metabolic heat.

Some organizations use the WBGT Heat Stress Index. The index uses dry bulb, wet bulb, and globe temperatures that are weighted to indicate the impact of each measure on the worker:

- Wet bulb (humidity) accounts for 70%
- Black globe (radiant heat and air movement) accounts for 20%
- Dry bulb (air temperature) accounts for 10%.

The WBGT heat stress index does not take into account the cumulative effects of long hours of hard work or the impact of personal protective clothing and equipment. Studies of wildland firefighting indicate that while WBGT values occasionally rise to dangerous levels, the low humidity and high air movement characteristic of fire weather combine to improve evaporative cooling (Ramberg 1974).

Clothing

Personal protective clothing strikes a balance between protection and worker comfort. Australian researchers have concluded that:

> ***The purpose of firefighter's clothing is not to keep heat out but to let it out!*** **(Budd, Brotherhood et al. 1996)**

About 70% of the heat load comes from within, from metabolic heat generated by muscles during hard work. Only 30% comes from the environment and the fire. Studies recommend the use of loose-fitting garments to enhance air movement, cotton T-shirts and underwear to help sweat evaporate, and avoidance of extra layers of clothing that insulate, restrict air movement, and contribute to heat stress.

Individual Differences

There are individual differences in fitness, heat acclimatization, and heat tolerance. Some workers are at greater risk for heat disorders. The reasons include inherited differences in heat tolerance and sweat rate. Excess body weight raises metabolic heat production. Illness, drugs, and medications can also influence the body's response to work in a hot environment. After an illness, workers need time to regain acclimatization to the heat.

Because a number of drugs increase the risk of heat stroke, workers should check with a physician or pharmacist if they are using prescription or over-the-counter medications, or if they have a medical condition. Large doses of the over-the-counter anti-inflammatory drug ibuprofen can cause kidney damage when ibuprofen is used by persons who are dehydrated.

Prevention

The consequences of heat stress can be avoided by improving the level of fitness and becoming acclimated to the heat.

Fitness

Maintaining a high level of aerobic fitness is one of the best ways to avoid heat stress. The fit worker has a well-developed circulatory system, and increased blood volume; both are important for regulating body temperature. Fit workers start to sweat sooner, so they work with a lower heart rate and body temperature. They adjust to the heat twice as fast as the unfit worker. They lose acclimatization more slowly and regain it quickly. In a heat chamber study conducted in the University of Montana Human Performance Laboratory (Cordes and Sharkey 1995), fitness was inversely related to the working heart rate. A subject with a high level of aerobic fitness (68 mL/kg-min) worked at a heart rate of 118 bpm (beats per minute), while a less fit subject (45 mL/kg-min) had a heart rate above 160 bpm while doing the same work (Figure 2). In this 2-hour treadmill test conducted at 90 °F, differences in fitness overshadowed the effects of variations in clothing systems.

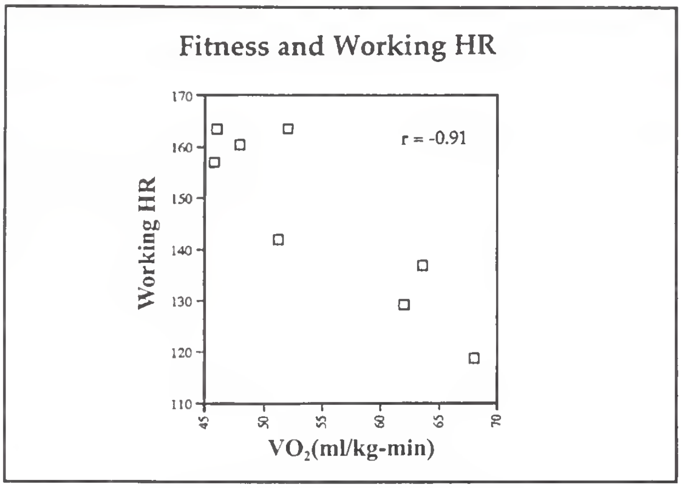

Figure 2—Fitness and HR Graph.

Acclimatization
Acclimatization is necessary to prepare a firefighter for work in heat stress conditions. Acclimatization is a process of adjustment that occurs in 5 to 10 days of heat exposure as the body:

- Initiates sweating at a lower temperature
- Increases sweat production
- Improves blood distribution, and
- Decreases the heart rate, and skin and body temperatures.

Acclimatize by gradually increasing work time in the heat, taking care to replace fluids and to rest as needed. Acclimatization can be maintained with periodic exposure to work or exercise in a hot environment.

On the Job
When heat stress conditions exist, workers must modify the way they work or exercise. When possible, workers should:

- Pace themselves
- Avoid working close to heat sources
- Do harder work during cooler morning and evening hours,
- Change tools or tasks to minimize fatigue, and
- Take frequent rest breaks during work.

Most important of all, workers must maintain hydration by replacing lost fluids.

Hydration
Studies of wildland firefighters indicate that fire suppression activities generate approximately 7.5 kilocalories of heat each minute worked, or over 400 kilocalories for each hour. Additional heat (about 180 kilocalories per hour) comes from the environment and the fire.

$$400 + 180 = 580 \text{ kcal/hr}$$

Complete evaporation of 1 liter of sweat removes 580 kilocalories of heat. That means that a firefighter needs to evaporate about 1 liter (1 L = 1.06 qt) of sweat for each hour of work. Body fluids must be replaced if sweating is to be maintained. That means drinking before, during, and after work.

Before Work—Drink 1 to 2 cups of juice or water before work. Avoid excess caffeine since it hastens fluid loss in the urine. Studies of glycerol-induced hyperhydration did not support its use for wildland firefighters (Swan 1997).

While Working—Workers should take several fluid breaks every hour, drinking at least 1 quart each hour. They should drink as much as possible during the lunch break. Water is the body's greatest need during work in the heat. However, studies show that workers drink more when lightly flavored beverages are available. Providing a portion of fluid replacement with a carbohydrate/ electrolyte beverage will help retain fluids and maintain energy and electrolyte levels. The carbohydrate also helps maintain immune function (Nieman 1998) and mental performance (Puchkoff et al. 1998). Caution workers to avoid sharing water bottles except in emergencies.

After Work—Continue drinking to replace fluid losses. Thirst always underestimates fluid needs, so workers should drink more than they think they need. Rehydration is enhanced when fluids contain sodium and potassium, or when foods with these electrolytes are consumed along with the fluid.

Sodium lost in sweat is easily replaced at mealtime with liberal use of the salt shaker. Unacclimatized workers lose more salt in the heat so they need to pay particular attention to salt replacement. But salt intake should not be overdone; too much impairs temperature regulation, and excessive salt can cause stomach distress, fatigue, and other problems. Make potassium-rich foods like bananas and citrus fruits a regular part of the diet, and drink lots of lemonade, orange juice, or tomato juice. In fire camp, limit caffeine drinks such as coffee and colas because caffeine increases fluid loss in the urine. Alcoholic drinks also cause dehydration.

Hydration can be assessed by observing the volume, color, and concentration of urine. Low volumes of dark, concentrated urine, or painful urination indicate a serious need for rehydration. Other signs of dehydration include a rapid heart rate, weakness, excessive fatigue, and dizziness. Rapid loss of several pounds of body weight is a certain sign of dehydration. Workers should rehydrate before returning to work. Continuing to work in a dehydrated state can lead to serious consequences, including heat stroke, muscle breakdown, and kidney failure.

Summary

The risk of heat stress and heat disorders can be reduced dramatically if workers comply with the following guidelines:

Prevention
- Improve or maintain aerobic fitness
- Acclimate to the heat

On the Job
- Be aware of conditions (temperature, humidity, air movement)
- Take frequent rest breaks
- Avoid extra layers of clothing
- Pace yourself
- Change tasks or tools

Hydrate
- Before work—drink several cups of water or juice
- During work—take frequent fluid breaks (1 qt/hr)
- After work—keep drinking to ensure rehydration (carbohydrate/electrolyte drinks increase fluid intake, decrease loss, provide energy, and help maintain immune function and mental performance)

Partner
- Always work or train with a partner.

It is dangerous to work or exercise alone in heat stress conditions. Firefighters should always train and work with a partner who can help in the event of a problem. Partners should remind each other to drink lots of fluids, keep an eye on each other, and start treatment immediately if their partner shows signs of a heat disorder.

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Cordes, K.; Sharkey, B. 1995. Physiological comparison of protective clothing variations. Medicine and Science in Sports and Exercise.

The standard on protective clothing and equipment for wildland firefighters (NFPA #1977, 1993) addresses outer garments and some accessories. This study describes a comparison of proposed uniform variations. Four male and 4 female volunteers performed prolonged (2 hour) treadmill tests with 4 variations of the standard uniform: no T-shirt (NT), a short sleeve T-shirt (ST), a long sleeve T-shirt (LT), and a ST plus a shroud for face and neck protection (SH), with test order determined by a balanced Latin square design. Two hour tests, conducted with a 3 day rest interval, consisted of a treadmill walk at 5.65 km/hr (3.5 mph) and 4.5% grade, with a 10.9 kg (24 lb) pack, reflecting the energy expenditure of firefighting tasks (6.5 Mets). The test was conducted at 32.2 C (90 F) and 30% RH, with an airspeed of 5 km/hr (3.1 mph), and with radiant heat (0.1 watts/cm2) during the first half of each hour. Heart rates, skin and tympanic temperatures, and perceived exertion (RPE) were recorded every 10 min, and weight loss and evaporative loss were determined after each trial. Male and female values were not significantly different so the data were pooled for repeated measures ANOVA. Significant order effects were found for HR and RPE ($p < .029$ and .0001 respectively), indicating some acclimatization. Analysis of treatment effects did not reveal significant differences, although HR, RPE, weight and evaporative loss tended to be greater for the LT. Tympanic and mean body temperatures tended to be higher with the SH. Individual differences in fitness overshadowed the effects of clothing variations. Treatment differences were more pronounced at 2 vs. 1 hour, and the radiant heat influenced the skin temperatures.

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Puchkoff, J.; Curry, L.; Swan, J.; Sharkey, B.; Ruby, B. 1998. The effects of hydration status and blood glucose on mental performance during extended exercise in heat. Medicine and Science in Sports and Exercise.

This study examined the differential effects of three hydration methodologies (carbohydrate, glycerol, and placebo) on the mental performance of 10 subjects during 3 hours of treadmill walking and simulated line digging in a heated environment. Each subject completed one three-hour exercise trial for each hydration methodology. The Paced Auditory Serial Addition Task (PASAT) was used to assess mental performance; each subject was given 3 practice tests before the first actual trial. The test required subjects to add pairs of single-digit numbers heard via a tape recorder and respond verbally. A set of 61 numbers was given at 3 speeds for each PASAT test and subjects were given the test 3 times during each trial. All subjects completed a VO_2 peak test and intensity for each trial was set at 50% of this value. Measures of blood glucose, plasma volume, body weight, rates of perceived exertion (RPE), heart rate, core and tympanic temperatures, and urine output were recorded at regular intervals throughout each trial. A statistically significant difference between final scores in the carbohydrate and placebo trials was found at the speed of one digit every 1.6 seconds ($p = 0.017$). At a speed of one digit every 1.2 seconds, scores after 90 minutes and at the end of 180 minutes of exercise were significantly higher than baseline scores ($p = 0.001$). The carbohydrate trial showed significantly higher values than the placebo trial. Females maintain more consistent body weights than males at the end of the exercise trial ($p = 0.0001$). Males gained more weight than females during the 90 min pre-hydration period ($p = 0.0004$). The glycerol trial resulted in significantly higher plasma volume values following the pre-hydration period ($p = 0,04$). Females exhibited a greater ability to maintain plasma volume ($p = 0.046$). Blood glucose values were higher at all data collection points, beginning with 60 minutes, during the carbohydrate trial ($p = 0.0001$). RPE scores were significantly higher than baseline measures ($p = 0.0001$) beginning at 90 minutes of exercise. The results of this study suggest that mental performance is facilitated after long-duration submaximal exercise in a heated environment, and is better maintained with carbohydrate than with glycerol or water. The increase in scores could be attributed to a narrowing of attentional focus and arousal of the central nervous system. The improvement with carbohydrate is most likely due to the increase in blood glucose which facilitated brain function.

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Swan, J. 1997. Glycerol-induced hyperhydration during long-term exercise in a heated environment. Unpublished master's thesis, University of Montana.

The ability to hyperhydrate has been shown to negate the effects of hypohydration due to long-term exercise in a heated environment. The purpose of this study was to examine the efficacy of two hyperhydration strategies during exercise heat stress and the resulting physiological strain. Ten trained subjects (5 M, 5 F) performed 2 three-hour exercise trials in a heat chamber (32 C). Exercise trials included 2 hydration regimens and were completed in a randomized double-blind fashion. The experimental solution contained 1 g glycerol/kg BW mixed with 21.4 ml water/kg BW. The control solution was the same as the experimental solution without the addition of glycerol. Solutions were ingested over a period of 90 minutes prior to the extended work bout. During the work bout subjects completed treadmill walking (50% VO_2 max) and simulated fireline building. This design was used to simulate a typical wildland firefighting work protocol. Subjects were given water to drink during the exercise so that the total amount of liquid taken in was equal to 5 ml/kg per 30 minutes, accounting for the amount of saline needed to keep the venous catheter open. Following the extended work bout, a performance trial was done on the digging treadmill. No significant difference was found between the two hydration strategies for the variables of heart rate, plasma osmolality, core temperature, sweat rate, % body weight loss, plasma volume changes, and post-exercise performance. The data did show that the glycerol hyperhydration strategy resulted in a significant reduction in urine output over the length of the entire trial ($p<0.05$). These data suggest that glycerol is distributed throughout all fluid compartments and not just extravascularly as previously thought. Based on the data collected it was concluded that there was no difference between the two hyperhydration strategies when rehydration was maintained during the exercise heat stress. Further research should consider the mechanism of glycerol's ability to increase TBW, and gender differences in response to an exercise heat stress.

Wildland Firefighting and the Immune Response

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Introduction

Wildland firefighters perform their jobs in a number of conditions (such as smoke, stress, and extreme temperatures) that may suppress their immune systems and ultimately affect their performance and increase the risk of disease or infection. The focus of this review is to examine the influences of external and internal stresses on immune function and present a military example (containing many of the stresses found in wildland firefighting) of a field nutrition study where immune suppression was minimized.

The Immune System
The immune system is an intricate system of organs, tissues, cells, and molecules that maintain balance between the environment and man. Stress such as physical exertion, sleep deprivation, malnutrition, extreme temperatures, psychological pressures, and endocrine changes all influence the body's defense system and alter its equilibrium.

The environment in which we live contains a great variety of infectious microbes (viruses, bacteria, fungi, parasites, and protozoa). If these multiply unchecked within a host, they can cause sickness, disease, and ultimately death. Our bodies combat these microorganisms through immune responses. For example, the first line of defense is the skin. Few infectious agents can penetrate intact skin; however they may gain access across epithelia, or gastrointestinal or urogenital tracts. Once an organism has gained access into the body, the immune system must recognize the pathogen or foreign material and mount an attack (immune response).

Immune responses are coordinated primarily by white blood cells (leukocytes). Leukocytes include monocytes, lymphocytes, basophils, eosinophils, and neutrophils. Each cell type typically performs several functions (Figure 1). The initial response to an invading organism is both nonspecific (innate) and specific (adaptive or acquired) recognition. Once the white blood cells identify the foreign material, the immune system mounts an attack to bind and destroy it (for instance, through phagocytosis). The immune response is like an orchestra. When cells and organs (the instruments) are working together, it functions very effectively; if cells are not functioning properly, there is dysregulation (disharmony). The risks of disease and illness are greater.

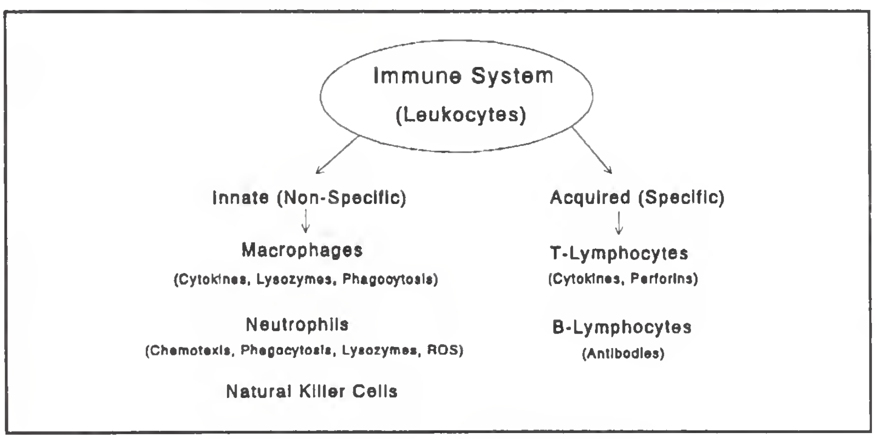

Figure 1—Leukocytes and the immune system.

Immune cells communicate by lymphokines (cytokines) that are small proteins secreted by leukocytes to act as molecular signals. As cellular communication molecules, they are analogous to hormones or neurotransmitters. In most cases, cytokines bind to specific receptors on cellular surfaces. These cytokines are not antigen specific, but perform a function to transduce or amplify a signal that ultimately translates into a cellular response. Cytokines may also have a systemic effect. For example, with an infection, leukocytes are stimulated and produce cytokines that can elevate the normal temperature (along with pyrogens from the invading organisms), causing fever. The effectiveness of the immune system can be evaluated by the quantification of the specific cytokines (the level at which they are secreted by leukocytes) and by the number of cells secreting specific cytokines.

Energy and sleep deprivation, mental stress, and intense physical exertion affect both innate and specific immunity [such as cell-mediated humoral (antibody production) and lymphocyte proliferation (multiplication of cells) following *in vitro* mitogen stimulation)]. The specificity and effectiveness of the immune system is the result of interaction and function of specific lymphocyte subsets. Immune effector cells, B-lymphocytes, natural killer cells (large granular lymphocytes), and T-lymphocytes interact to mount a defense against invading pathogens or abnormal cells. B-lymphocytes are involved with antibody production, while T-lymphocytes are most commonly associated with cell-mediated immunity. T-lymphocytes, in addition to their role as "killer cells," have important roles in regulating B-lymphocyte functions and in "directing" cellular trafficking in the development of highly specific antibody responses. In a clinical setting, numerous laboratory tests can be performed to evaluate immune function (Table 1).

Table 1—Examples of laboratory immune function assessment.

White Cell Numbers

- Automated cell count (complete blood count)
- Flow cytometry (differential cell population analysis by immunophenotype analysis)

Cell Function

- Lymphocyte proliferation following mitogenic stimulation
  - Tritiated thymidine uptake
- Gene Regulation
- Cytotoxicity
  - NK cell cytotoxicity
  - Lymphokine-activated cytotoxicity
  - Antigen-specific CD 8+ cytotoxicity
- Cytokine Production
- T- and B-lymphocyte cooperation
  - CD40 ligand expression
- Immunoglobulin production
  - Antibody response to vaccination

***In Vivo* Immunity**

- Cutaneous reaction
  - Delayed-type skin hypersensitivity
- Resistance to viral infections
  - Rhinovirus challenge
- Incidence of infectious disease

Immune cells are identified by their morphology (size and structure), function, and specific proteins on their surface. Immune cells can be analyzed by flow cytometry. There are also a number of ways to evaluate the functions or numbers of immune cells.

In vitro tests may not, in all cases, be indicative of clinically relevant immune deficiencies because they provide a limited view of immune status. Furthermore, *in vitro* studies need to be performed on fresh blood samples. A single test will usually not be indicative of overall immune system status. When evaluating immune status or competency, it is important to evaluate a variety of cellular functions or components. It is also important to attempt to quantify overall immune system effectiveness by using clinical measures such as delayed type-skin hypersensitivity (DTH), rate of infection, or response to pathogen or vaccine. DTH tests can be easily administered by placing small amounts of proteins that cause a reaction (antigens) into the epidermis and superficial dermal tissue. Circulating T-lymphocytes that have had prior contact with the antigen induce a specific immune response that causes lymphocytes to undergo mitosis (proliferation) and release a number of soluble mediators (cytokines). The intensity of the response reaches its peak within 24 to 72 hours (thus the term delayed). The diameter of the bump (induration) can be measured in millimeters. The larger the induration, the better the immune response. Lack of a response is called anergy. Anergy indicates functional impairment of the immune system (with the assumption that the individual has had prior exposure to the antigen). Experience with DTH over the last several years has shown good correlations between lack of DTH reactivity (anergy) and risk of infection and mortality in a hospital setting (Table 2).

Table 2—Infection and death rates based on Delayed Type-Skin Hypersensivity (DTH) skin testing of 4,289 hospitalized patients (Christou et al. 1995).

	Infection Rates	Death Rates of Infected
Reactive‡	172/2509 (7%)	33/172 (19%)
Relative Anergy*	109/666 (16%)	35/109 (32%)
Anergy†	289/1114 (25%)	147/289 (51%)

‡Intradermal injection into the forearm of *Candida*, mumps skin test antigen, purified protein derivative, trichophyton and varidase. Reactive was defined as a diameter of induration equal to or greater than 5 mm.

*Response to one of five antigens.

†No response to any of the antigens.

Patients who are DTH reactive have a much lower rate of infection. Those patients who are anergic and become infected have a poor prognosis. A reduction in cell-mediated immune responses can limit the development of an effective immune response against intracellular pathogens, including viruses, bacteria, fungi, and protozoa. DTH has also been used to evaluate the immune function of malnourished, trauma, or immune-suppressed patients.

Stresses of Firefighting and Influence on Immune Function

The immune response can be influenced by a number of factors, including the intensity and duration of physical and/or psychological stress, concentrations of hormones and cytokines, body temperatures, hydration status, hormones, and ambient temperature. Wildland firefighters are exposed to many "stresses" that can impact their health and influence their immune systems. In addition to the psychological challenges, wildland firefighters are exposed to a number of physical challenges (such as environmental toxins, injuries, smoke inhalation, abrasions, laceration, and burns) that suppress the immune system. Although there have been many studies evaluating the effectiveness of firefighting equipment for the wildland firefighter, little research has focused on the firefighter's health [other than respiratory health (Harrison et al. 1995)]. Therefore, we will examine other scenarios to evaluate some of the factors that may influence the immune system of the wildland firefighter.

Stress and Infection

The first question is: What happens to the immune system as a result of stress? Secondly, do these changes translate into increased susceptibility? Peterson et al. (1991) reviewed stress and the pathogenesis of infectious disease. The authors reviewed many studies in which stressors (swimming or running, electric shock, isolation or crowding, and exposure to cold temperatures) were imposed on animals and mortality was studied. Table 3 is a sampling of results showing the effects of physical stress on the susceptibility of animals and humans to viral infections.

Table 3—Animal models of stress and viral infection (modified from table of Peterson et al. 1991).

Virus	Animal	Stressor	Finding
Poliomyelitis	Mouse	Forced exercise	↑* Mortality, paralysis
Coxsackievirus B	Mouse	Forced Exercise	↑ Mortality
Herpes simplex	Mouse	Restraint	↑ Mortality
Influenza A	Mouse	Forced exercise	↑ Mortality
Infectious Mononucleosis	Human	Pressure to achieve academically	↑ Clinical illness
Upper respiratory tract infection	Human	Life events	↑ Frequency and severity
Upper respiratory tract infection	Human (Marines)	Delayed promotion	↑ Frequency
Epstein-Barr virus	Human (Medical school students)	Academic Stress	↑ level of antibody, indicating high infection rate

*↑ = Increased.

Research indicates that moderate exercise enhances immunity while more strenuous exercise and prolonged training appear to suppress it (Simon 1987; Nieman 1991; Nieman et al. 1993). There have been studies of relatively short-term physical stress, yet few studies have examined the chronic stress that may be experienced by wildland firefighters. This offers a unique opportunity for investigation.

Cowles reported in 1918 that pneumonias were associated with intensive exercise. It has more recently been shown that unusually high rates of upper respiratory tract infections (URTI) can be attributed to either a single bout of exhausting exercise or overtraining (Douglas and Hanson 1978; Peters and Bateman 1983; Nieman et al. 1989). Table 4 shows several animal studies that linked increased mortality by bacteria with forced exercise and crowding.

The idea that high-intensity training might reduce immune function was first postulated in 1932, based on the observation that muscular fatigue predisposed individuals to infections, especially respiratory pathogens (Baetjer 1932). Several epidemiological studies have documented an increased incidence of URTI following strenuous exercise (Neiman et al. 1989; Peters 1983; Peters et al. 1993). Conversely, persons performing moderate exercise have lower risk of infection than sedentary controls (Heath et al. 1992; Neiman et al. 1993). These results are also supported by studies in which mice undergoing moderate exercise training had reduced susceptibility to bacterial and protozoan infections compared to sedentary controls (Cannon and Kluger 1984; Chao et al. 1992).It appears that the effect of moderate exercise can convey enhanced immunological responses. More chronic and severe stress, as in military training such as the U.S. Army Special Forces Assessment and Selection School (SFAS), decreases immune function and increases susceptibility to environmental pathogens.

Table 4—Increased mortality by bacteria in animals with forced exercise and crowding.

Bacteria	Animal	Stressor	Finding
Bacillus anthrcis	Rat	Forced exercise	↑ Mortality
Staphylococcus aures	Rabbit	Forced exercise	↑ Mortality
Salmonella typimurium	Mouse	Crowding	↑ Mortality
Mycobacterium tuberculosis	Mouse, rat	Forced exercise	↑ Mortality

Ambient temperatures can also influence immune function and susceptibility to infection. For example, Shimizu et al. (1978) found that pigs maintained at 30 °C (86 °F) remained disease-free after a challenge with coronavirus. However, the pigs experienced diarrhea from the virus challenge when the ambient temperature was lowered to 4 °C (39 °F). Similarly, temperature changes (stress) can also influence susceptibility to bacteria. For example, Previte and Berry (1962) demonstrated that mice exposed to temperatures of 5 °C (41 °F) had markedly increased susceptibility to bacteria or lipopolysaccharide.

One area that has not received much attention is the gender-specific influence of stress upon infectious morbidity or mortality. Tobach and Bloch (1956) injected female and male mice with *Mycobacterium tuberculosis* and then imposed the stress of crowding on the animals. They found that crowding female mice offered protection to the infection while the stress of crowding male mice increased the death rate.

Lack of sleep has been shown to adversely affect immune function. For example, it has been shown that sleep deprivation in the rat causes drastically increased food consumption (hyperphagia), yet the rats experience body weight loss (malnutrition-like symptoms) and succumb to lethal opportunistic systemic infection. Furthermore, sleep-deprived rats develop skin lesions that are not inflamed, indicating immune dysregulation (Kushida et al. 1989). Other researchers noted that cutaneous changes were often the first signs of primary alteration in the susceptibility of the host to pathogens. The immune system was the first system to fail after sleep deprivation (Everson 1995).

Complaints by wildland firefighters of upper respiratory tract problems are the main reasons for visits to the medical clinics. URTI can result from decreased immune function from fatigue, sleep deprivation, smoke exposure, inadequate nutrition, or a combination of stresses.

Readiness and Impact on Time Lost

The influence stress has on immunological defenses that result in lost hours or prevent readiness for wildland firefighters has not been reported. However, military studies can be used to establish the impact of immune changes observed during military environments and infection rates or nonbattle injuries. Historical studies examined findings from research conducted during

military conflicts. For example, in several of the major military conflicts involving the United States, disease and nonbattle injuries (DNBI) have accounted for significant loss of manpower (Palinkas and Coben 1988). During World War II the ratio of Navy and Marine Corps hospital admission for DNBI and combat-related wounds and injuries was 88:1. In Marine Corps personnel serving in Vietnam, for every 100 men wounded in action, 128 men were hospitalized for DNBI (Palinkas and Coben 1988). Exposure to pathogens from environmental factors and crowded living quarters contribute to disease susceptibility of military units even during routine peacetime operations. Seay (1995) found that after a 10-day port visit to Rhodes, Greece, by the crew of the USS Forrestal, 777 cases of gastroenteritis were reported. This accounted for 15% of the work force and a cost of 462 man-days of lost work. Major Wallace J. Seay stated, "⌉ lost duty days, and the burden of providing medical confinement may be more critical than fatal illnesses. Fatalities may be replaced but sick soldiers continue to occupy positions, decrement performance, and consume large quantities of medical supplies (Seay 1995, pp. 3-4)." While many factors may contribute to susceptibility to infection and disease during military operations, the effect of both physical and psychological stress undoubtedly have a significant impact on host defense mechanisms. Therefore, it would be important to evaluate the stress that is experienced by wildland firefighters, its impact on immune function, and its influence on firefighters' readiness to perform.

Physical and Nonphysical Stresses

There is evidence to suggest that with chronic physical exertion, immune dysregulation occurs [low immunoglobulin and complement levels, increased neutrophil concentration yet decreased phagocytosis, decreased NK cell activity, decreased lymphocytic proliferative response and T lymphocyte numbers (Nieman 1997)]. Furthermore, infections and intense exercise have similar immunological responses [leukocytosis, lymphopenia≡primarily T lymphocytes, degranulation of neutrophils, and decreased lymphocytes' responsiveness to mitogens (Heath et al. 1992)].

Stress, such as exertion and extreme environmental temperature, can play a role in immune dysregulation. The resulting changes are similar to nonphysical stresses (such as isolation). Comparisons of the effects of cold, exertion, and isolation on immune function were studied in a cold-water, swimming mouse model and in an isolation model. Ben-Nathan and Feuerstein (1990) exposed mice to cold water (5 min/day) for 8 to 10 days and also stressed a group of mice by isolation. Animals were then exposed to a West Nile Virus (WNV-brain specific virus) at the initiation and after 5 days of cold stress (Figure 2a). It was found that physical (cold water and swim stress) or nonphysical (crowding stress) had a significant impact on reducing the weight of important immune organs (thymus and spleen) as well as increasing mortality rates (Figures 2a, 2b).

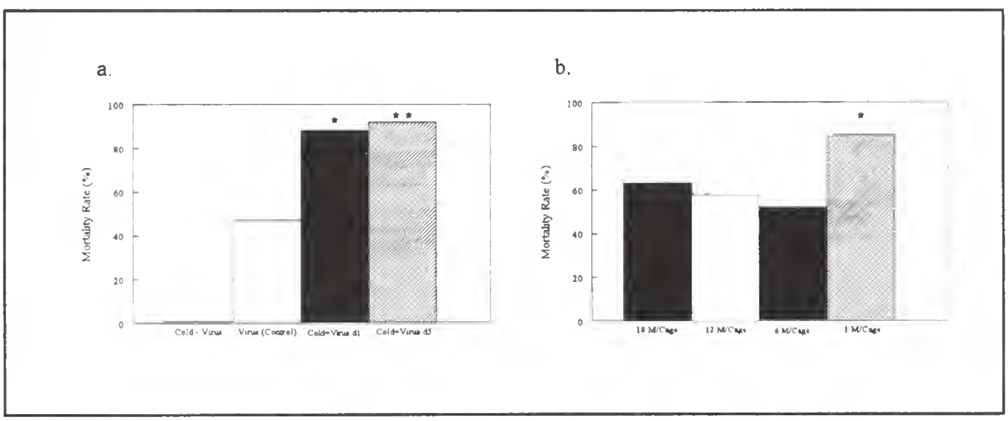

Figure 2a≡The effect of cold stress on the mortality of mice inoculated with West Nile Virus: Cold-Virus (not infected), Virus (Control), Cold+Virus d1 (cold stressed and infected on day 1 with 50 PFU), Cold+Virus d5 (cold stressed and infected with 50 PFU on day 5 of stress).
**p* < 0.05 that the difference was due to chance.
***p* < 0.001 that the difference was due to chance.

Figure 2b≡The effect of isolation or crowding stress on the mortality of mice inoculated with WNV. 18 M/Cage (18 mice/cage), 12 M/Cage (12 mice/cage), 6 M/cage (6 mice/cage-normal housing), 1 M/Cage (1 mouse/cage),
*p < 0.01 compared to normal housing.
(modified from Ben-Nathan and Feuerstein 1990).

In human studies, nonphysical and physical stress can produce immunological changes. Spousal caregivers of patients having Alzheimer's or dementia disease have been shown to have lower immune responses (response to vaccine and cytokine response). Caregivers were vaccinated with a trivalent influenza vaccine. Their antibody responses were compared to a control group (noncaregivers). Although caregivers and noncaregivers had similar baseline antibody titers, the caregivers responded less often and with less magnitude than the control group. Furthermore, the cytokine response was lower in the stressed caregiver group as well (Figure 3).

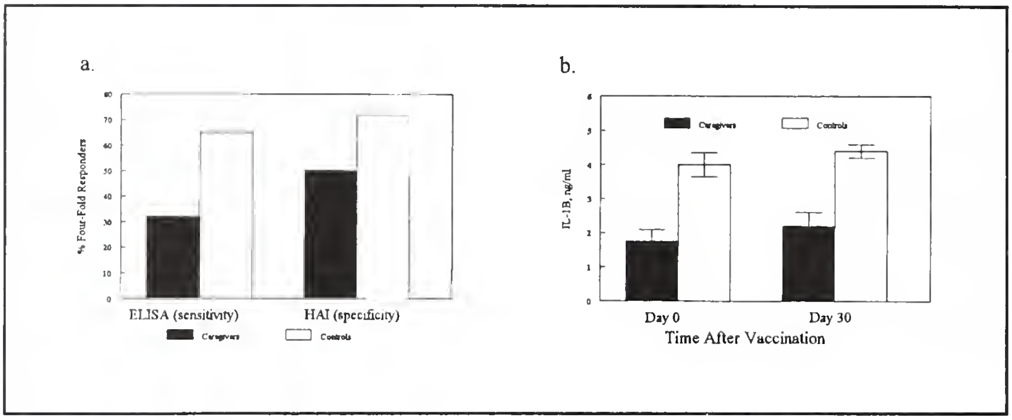

Figure 3a—Percentage of caregivers and controls with a four-fold increase in antibody 30 days after vaccination. The ELISA assay has greater sensitivity, while the hemagglutinin inhibition (HAI) assay has greater specificity.

Figure 3b—IL-1 β responses of monocytes to lipopolysaccharide stimulation (mean ± SEM) of caregivers and controls before and 30 days after influenza vaccination (from Kiecolt-Glaser et al. 1996).

The caregivers' stress adversely affected the immune response (as measured by antibody and cytokine responses), placing them at increased risk of infection.

Thermal Injury

Thermal burn injuries of a large body surface area induce a systemic inflammatory response that also is associated with immune dysfunction (Lyons et al. 1997; O'Sullivan et al. 1995). The immunological effect of smaller thermal burns has not been extensively studied. There are indications that tissue and systemic antioxidant concentrations decrease after smaller thermal burns (Rock et al. 1997), which could impact immune function. Furthermore, burn injury predisposes burn patients to infections, poor wound healing, and increased nutrient requirements. Nutritional strategies to support the health of the burn patient requires diets of highly bioavailable protein, containing specific components that may aid in maintaining or strengthening the immune system.

Chemicals in smoke that wildland firefighters may be exposed to can affect the immune system. Smoke exposure has been a recognized health issue for fire management for many years (Liu et al. 1992). A few studies in the 1970's hinted that smoke exposure contributed to fatigue and injuries. The main inhalation hazards are carbon monoxides, aldehydes, benzene, acrolein, and respirable particulate matter (Materna et al. 1992). Firefighters occasionally report illness from exposure to smoke. Links between smoke exposure and morbidity are not currently understood.

Nutrition

Starvation has also been shown to affect the immune system. For example, starvation causes involution of the thymus (primary immune organ), it reduces cytokine production, reduces the numbers of T-lymphocytes, and increases incidence of infection. Zaman et al. (1997) studied malnutrition in children from Bangladesh and found that modest malnutrition reduced immunocompetence and increased the incidence of upper respiratory tract infections. Results indicated that children that were anergic to DTH (delayed type-skin hypersensitivity) had a 20% higher risk of developing an upper respiratory tract infection.

Nutritional Strategies to Overcome Stress-Induced Immune Dysfunction

Nutritional deficiencies or suboptimal nutrient levels can be the result of inadequate intake, decreased absorption, or increased

utilization of nutrients. Furthermore, many nutrients are required for optimal functioning of the immune system. Therefore, when nutrients are depleted or when nutrients have been suboptimal, immunological impacts place an individual at risk of infection. The inpacts include:

- Impairing the immune cells from recognizing foreign stimuli
- Altering the proliferative responses of the immune cells
- Impairing the antigen presentation
- Reducing the killing capacity of the immune cells
- Changing the membranes or cooperative interaction between the various cell types involved in the immune system.

Once an individual has become infected, increased nutrient utilization or malabsorption occurs, which further increases the individual's nutritional requirements (Figure 4). Medications and antibiotics may disrupt gastrointestinal flora, exacerbating diarrhea (decreasing absorption) and compromising the nutritional state. Nutritional supplementation can influence nutritional status and ultimately impact immune function. There are also many interactions between nutritional status and immune function in this cycle.

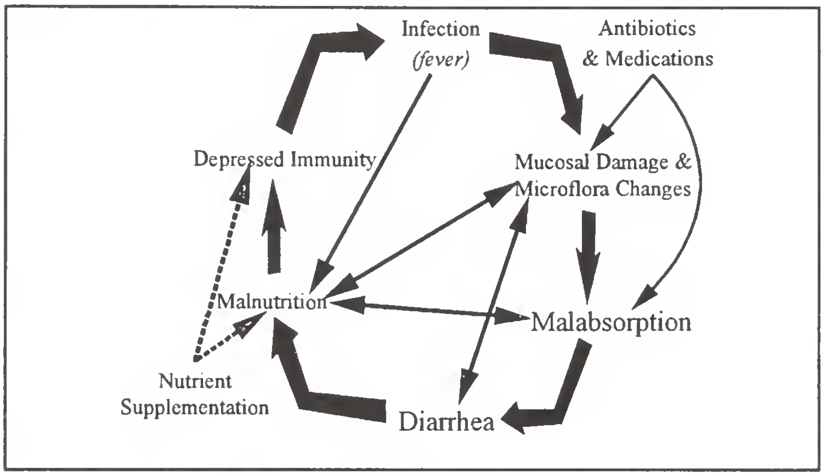

Figure 4—Nutrition and immunity cycle.

The effect of infection on nutritional status is characterized by wasting of peripheral tissues, particularly lean body mass (muscle). This seems to be the result of cytokine-mediated responses designed to support the immune system and fight against infection. Paradoxically, these mediators, when secreted in excessive or inappropriate amounts, have been associated with morbidity and mortality in a wide range of conditions (such as rheumatoid arthritis, inflammatory bowel disease, and sepsis). Nutrients (vitamins and minerals) are used as substrate and co-factors for immune cells. Once an infection takes place, immune cells have a higher requirement for nutrients (see Figure 4 outlining the concept and interactions). Furthermore, upon infection, particularly of the gastrointestinal tract, there is mucosal damage and the microflora of the gut changes. The absorptive capacity of the small intestine decreases, leading to malabsorption. The mucosal and microflora changes can also be influenced by antibiotics and medications as well as by decreases in the effectiveness of nutrient absorption. This damage may cause diarrhea, further compromising the nutritional status and suppressing immune function, which further compromises the body's ability to fight the infection. Nutrient supplementation can prevent malnutrition and provide the essential factors immune cells need to function optimally. An infection may also cause increased utilization of nutrients, influencing nutritional requirements.

To demonstrate the importance of an optimal level of nutrients, Chandra reported (1996) that inadequate nutrient consumption hampers the immune system's ability to fight an infection. He fed mice approximately 40% of the nutrient requirement for 3 weeks, and then challenged the mice with *L. monocytogenes* intraperitoneally. These mice had a survival rate approximately half that of mice fed an adequate level of nutrients (Figure 5). Nutrition impacts the immune system by providing essential components for immune cells to function properly. Nutrition presents a possible strategy to combat immune suppression induced by stress. Adequate nutrients will provide for optimal immune function. Chandra stated, "The era of nutritional manipulation of the immune system has finally dawned and it brings with it the promise of using diet and nutrition as innovative powerful tools to reduce illness and death caused by infection" (Chandra 1996, p. 1,430).

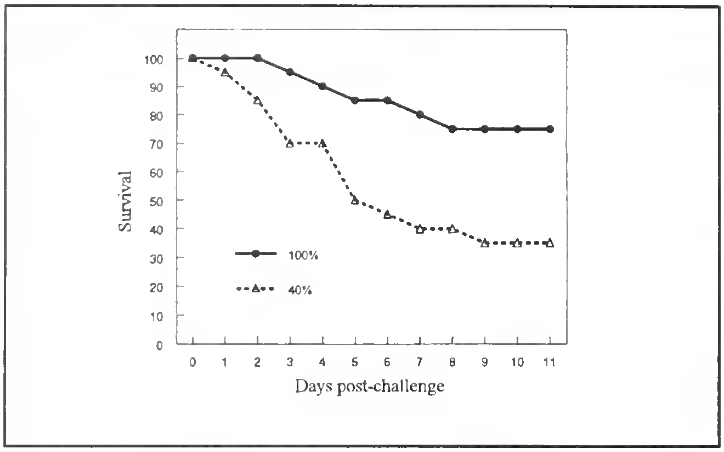

Figure 5—Eight-week-old C57Bl/6 X DBA/2F1 hybrid male mice were fed approximately 40% of the nutrient requirement for 3 weeks and divided into two groups (formula enriched with nutrients known to simulate the immune responses-100% group and the 40% formula group). After 2 weeks, the mice were challenged with 4 x 10^4 *L. monocytogenes* intraperitoneally. Survival was noted (Chandra 1996).

Nutrient supplementation can also affect immune function and counteract the stress-induced immune changes. Appendix A contains a summary table of many nutrients and their influence on immune function. Supplementation as a means to minimize or prevent immune changes and protect individuals who are undergoing physical stress has been studied to a limited extent. There are suggestions that nutrients such as vitamin C play a role in immune function and may prevent immune suppression in physically stressed individuals. Vitamin C is found in high concentrations in leukocytes and its concentration decreases rapidly during infections, which suggests that vitamin C is an important factor in immune function (Thomas and Holt 1978). Peters et al. (1993) supplemented the diets of ultramarathon runners for 21 days before an ultramarathon with either 600 mg vitamin C/day or a placebo. They then established the incidence of symptoms of upper-respiratory-tract infection during the 14 days after the race. Sixty-eight percent of the runners who consumed the placebo reported upper respiratory tract infections compared with 33 percent of those who consumed the C vitamin. It has also been shown that physical activity raises oxygen demand severalfold, increasing the formation of oxygen radical species (Giuliani and Cesaro 1997; Alessio 1993). As oxygen radical species are formed, they adversely affect immune function (Aruoma 1994). Theoretically, providing antioxidants in sufficient amounts during exercise-induced oxidative stress may prevent immune dysregulation (Witt et al. 1992). Several reviews on the importance of dietary components, such as antioxidants, and their influence on multiple aspects of the immune response and immune system have been published (Corman 1985; Chandra 1990).

Shepard and Shek (1995) postulated that athletes and other health-conscious persons may participate or adopt unusual nutrition programs that may influence their overall nutritional status and ultimately impact immune function. Furthermore, prolonged or chronic stress and exercise may deplete muscle glycogen or other nutrients and lead to competition with immune cells.

Few opportunities have existed to conduct well-controlled field research to study the effect of stress on immunological responses. Nutrition is an important factor that can be manipulated to minimize immune dysregulation during stressful situations. For example, it is not uncommon to observe diminished immune response (anergy) to DTH in individuals with severe malnutrition. The influence of mild malnutrition on immune regulation and an understanding of specific levels of nutrients for optimal nutrition remain to be investigated.

Nutritional inadequacies result in immune dysregulation and can profoundly influence susceptibility to infection. Cells of the immune system require a variety of nutrients for proper function. Furthermore, nutrients play a vital role in enzyme synthesis and activity required for normal immune function (many kinases and transferases require zinc). Garcia-Tamayo et al. (1996) found zinc treatment to chronically stressed mice ameliorated the metabolic and immunologic effects of chronic stress.

U.S. Army Special Forces Assessment and Selection Course and Ranger Training

Ross Products Division/Abbott Laboratories has investigated potential benefits of nutrient supplementation and nutritional

strategies to minimize immunologic changes in a variety of conditions. The difficulty has been in identifying models or clinical scenarios where immunologic dysregulation occurs and in having an opportunity to intervene with nutrients. One promising situation we have evaluated has been United States military training. The military stresses (such as carrying heavy packs and equipment, strenuous physical exertion, exposure to extreme temperatures, and psychological stress) seem to be similar to those experienced by wildland firefighters. A field study is summarized below, describing our findings.

Historically, soldiers during military deployment and wartime refugees have demonstrated an increased incidence of infectious diseases. Furthermore, soldiers in military training have also incurred higher than expected infectious disease outbreaks, pointing toward an underlying susceptibility. The U.S. Army Special Forces Assessment and Selection Course (SFAS) is highly demanding, both physically and emotionally (21 days duration). Fairbrother et al. 1995 documented a negative energy balance (1,379 kcals/day) in soldiers who participated in the course; however, there were no significant clinical manifestations of vitamin and/or mineral deficiencies. One observation from that study was a reduced lymphocyte proliferation response (reduced 23 percent on average) to mitogen stimulation. This observation suggested that multistressors (negative energy balance, sleep deprivation, physical activity, and psychological stress) may have negative effects on immune function and the ability of lymphocytes to combat infections. For example, Bernton et al. (1995) found that during U.S. Army Ranger training, DTH skin anergy increased over time and those that did respond had a decreased response (Table 6).

Table 6—Summary of Delayed Type-Skin Hypersensitivity (DTH) skin test from Ranger training (Bernton et al. 1996)

Week of training	Subjects (n)	Total induration	% Anergic
0	40	17.9±	0
6	40	10.5±1.0	2
8	26	6.3±1.0	15

The SFAS scenario provided a unique population because the soldiers have similar environmental factors (including diet and physical stress), suppressed immune function, and higher rates of infection than nonstressed soldiers. Nutrition intervention allowed for an evaluation of nutritional supplementation on immune function (suppressed in previous studies). Furthermore, military training scenarios permitted the evaluation of a large number of subjects in a short period.

Two hundred soldiers participating in a Special Forces Assessment and Selection School (SFAS) course conducted by the U.S. Army John F. Kennedy Special Warfare Center and School, Fort Bragg, North Carolina, volunteered to participate in this prospective, randomized, blinded, placebo-controlled study. The test group (n = 100 soldiers) was designated to consume their regular diet consisting mainly of meals ready-to-eat (MRE) plus a novel ready-to-feed treatment product (8 oz two times per day) containing antioxidants, minerals, and a structured lipid (from long- and medium-chain fatty acids), and indigestible carbohydrates. The control group (100 soldiers) consumed a ready-to-feed product of similar taste and appearance containing similar amounts of macronutrients and energy. Dietary intake, body weight change, and immune function were measured before and after the physically and psychologically demanding 21-day training course.

In the treatment group, 50 of 100 soldiers completed the course compared to 57 of 100 from the control group. Soldiers dropped from the course primarily for administrative or voluntary reasons. Rates were similar to previous courses in previous years. There were no differences between drop rates and reported intolerance to either product. Subjects lost approximately 6.4 pounds in 3 weeks. Combining the dietary intake with the weight loss data, it was estimated that soldiers had an energy expenditure of 5,040 kcals per day.

The *in vivo* measurement of overall cellular immune function, delayed type-skin hypersensitivity (DTH) at exit (total induration), suggested that subjects consuming the treatment product had a greater response ($P = 0.07$ that the difference was due to chance). Similarly, fewer subjects in the treatment group were DTH anergic (18% compared to 39% in the control group) to the skin test, suggesting a lower risk for infections in the treatment group. The percentage of soldiers in the control group who were anergic was consistent with previous studies in SFAS. By contrast, there was a trend toward increased lymphocyte responsiveness to mitogen stimulation from soldiers fed the treatment product. Several changes were noted in lymphocyte subsets during the course of the study. The pattern of change in white blood cells, lymphocyte numbers, and subsets was consistent with increased risk of infection within SFAS. The treatment product attenuated some of the changes. Cell profile changes in the treatment group also seemed to indicate that neutrophils may have been migrating to the target or affected tissues

(skin or lungs) rather than circulating in the blood. Maintenance of lymphocyte populations such as cytotoxic/suppressor, Th1 lymphocytes, and neutrophil phagocytosis were found in the group fed the treatment formula. Overall, the treatment formula appeared to minimize or attenuate the immunologic changes associated with SFAS training (strenuous physical and emotional stress).

A similar study was conducted during the 62-day Ranger training. We formulated a novel nutrition bar containing a nutrient profile similar to that of the ready-to-drink formula used in the SFAS study. The treatment bar lessened some of the immunological changes and appeared to help maintain weight better than the placebo product.

Conclusions and Future Focus

The immune system is an intricate and highly regulated network of cells, tissues, and molecules that aid in warding off infections and disease. Although the effectiveness of the immune response can be influenced by a number of stressors, specialized nutrition can minimize or prevent immune dysregulation.

No studies have been conducted to evaluate immune function in wildland firefighters. It seems logical that they would experience some level of immune suppression from the stresses to which they are exposed. It would be important to establish whether these individuals have increased risk of infection compared to nonstressed firefighters. If there is an increased risk or rate of infection, it would be valuable to study strategies (such as nutritional supplementation) that might influence the immune system under these conditions. Specific nutritional formulations tested in military training where the physical and psychological stresses may be similar to those of wildland firefighting may be of value to firefighters.

Appendix A

Summary table of nutrients and their influence on immune function.

Nutrient	Effect on immune function
Energy	Caloric deprivation associated with decreased antibody response, decreased anti-DNA antibodies, decreased/increased thymocyte proliferation in response to exogenous IL-2, and decreased/increased IL-2 production in response to stimulation with mitogens.
Protein	Deficiency affects all components of the immune system including depressed cell-mediated immunity, delayed hypersensitivity skin test, B-lymphocyte function, macrophages, neutrophils, and complement.
Arginine	Deficiency compromises cellular immune mechanisms, particularly T-lymphocyte function. Supplemental arginine increases thymic size and number of T lymphocytes, suppresses tumor growth, and decreases incidence of infection.
Glutamine	Energy substrate for macrophages and T lymphocytes.
Lipids n-6 fatty acids	Linoleic acid deficiency causes dermatitis and impaired wound healing. Prostaglandin E_2 (a metabolite of linoleic acid) may depress cytostatic functions, lymphocyte mitogenesis, production of lymphokines, cytolysis, facilitate tumor growth, and prolong allograft survival
n-3 fatty acids	n-3 fatty acid deficiency may induce neurological deficits, dermatitis and immunological changes; increased levels improve cell-mediated immune responses and opsonic indices, increase splenic weight, and inhibit production of immunosuppressive dienoic prostaglandins.
Zinc	Deficiency produces increased susceptibility to infection, depressed circulating thymic hormone, altered complement function, marked atrophy of the thymus; reduction in leukocytes (especially T-lymphocyte percentage) and antibody-mediated, cell-mediated, phagocytosis as well as delayed hypersensitivity skin test responses. Excessive intake causes specific defects in the function of T lymphocytes and granulocytes.

Iron	Deficiency produces impaired bacterial killing ability of phagocytic cells, impaired lymphocyte response to mitogen stimulation, and decreased rosette-forming T lymphocytes.
Selenium	Deficiency may impair antibody production and the bacteriocidal activity of neutrophils; slight excess may reduce susceptibility to infection and enhance antibody production and splenic plaque cell formation (immunostimulatory actions may be potentiated by vitamin E).
Manganese	Required for normal antibody synthesis and/or secretion; excess inhibits antibody formation and chemotaxis, and increases susceptibility to pneumococcal infection.
Magnesium	Deficiency can cause thymic hyperplasia, impair cell-mediated immunologic responsiveness, decrease serum IgG, IgG_2, IgA levels, and reduce hemagglutinin responses.
Copper	Deficiency associated with increased rate of infections, depressed immune system and microbicidal activity of granulocytes, impaired antibody response, and depressed thymic hormone.
Vitamin A	Deficiency may increase susceptibility to infection, cause atrophy of lymphoid tissues, decrease lymphocyte counts, suppress antibody production, reduce *in vitro* lymphocyte response to mitogens, suppress delayed dermal hypersensitivity, reduce mobilization of peripheral macrophages, and increase the serum concentration of hemolytic complement.
β-Carotene	Modest doses of β-carotene enhance immune responses.
Vitamin B_6	Deficiency depresses antibody production and delayed dermal hypersensitivity, and may cause atrophy of lymphoid tissues, decreased lymphocyte counts, and diminished inflammatory response.
Vitamin C	Deficiency may increase susceptibility to infection, reduce the percentage of T lymphocytes, prolong allograft survival, suppress the recall mechanism of delayed dermal hypersensitivity, impair the function of neutrophils and macrophages, reduce thymic humoral factors, and enhance complement concentration.
Vitamin D	Deficiency causes anergy in the delayed hypersensitivity skin test.
Vitamin E	Deficiency depresses immunological responses to antigens, lymphocytic proliferative responses, delayed dermal hypersensitivity, and general resistance. Slight excess enhances antibody responses to vaccines (effect is compounded by selenium deficiency), delayed type skin hypersensitivity, clearance of particulate matter by the reticuloendothelial system, and general resistance. Supplements containing vitamin E have shown enhanced immune function. Furthermore, supplementing the diets of elderly subjects minimizes the age-induced immune suppression
Folate	Deficiency may depress lymphocyte counts, antibody response to immunization, *in vitro* lymphocyte responses, and delayed dermal hypersensitivity.
Thiamine	Deficiency may depress splenic plaque-forming cell response to immunization.
Riboflavin	Deficiency generally depresses primary response of antibody production after immunization.
Pantothenic acid	Deficiency generally depresses antibody response to immunization and may depress splenic plaque-forming cell response to immunization.
Biotin	Deficiency may depress antibody response to immunization and splenic plaque-forming cell response to immunization.
Vitamin B_{12}	Deficiency may depress *in vitro* lymphocyte responses and neutrophil functions.
Multinutrients	Supplementation with multinutrient preparations have decreased incidence of nutrient deficiency, infection, and attenuated immune suppression/dysregulation.
Herbals & others	Echinacea, Ginseng, Gingko Biloba, St. John's Wort, Mother's Wort, Dehydroepiandrosterone (DHEA), Melatonin, Phytonutrients, soy extracts, undenatured whey protein, lactoferrin, polyclonal antibodies from milk or eggs. A variety of compounds have been found either in uncontrolled clinical studies, testimonials, animal studies, or *in vitro* studies to indicate some immunologic potential.

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Oxidative Stress and Antioxidants: Fighting the Fire Within

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Introduction

There is a fire smoldering within the cells of your body that could burst into flame at any moment. Scientists who study aging, chronic disease, and preventive medicine call the "smoldering fire" free radical production and the "flame" oxidative stress. As long as the fire just smolders, it is under control by endogenous antioxidant defenses. However, if it is fanned into "flame" by certain events such as exercise, inhalation of pollutants, excessive exposure to sunlight or poor dietary intakes of antioxidant nutrients, oxidative stress can rage out of control, inflicting cumulative damage to important tissues within the body. The damage is not always noticeable, but may exact a serious toll over time.

Consider this scenario: Jack Jones, wildland firefighter, is aboard an airplane on an unplanned flight. He left his home—now 200 miles behind—in haste. No time to eat or even tell the wife and kids goodbye. Five thousand acres of pristine wilderness forest is burning and his crew is assembling to help bring the fire under control. In 10 minutes he will be on the ground racing toward the blazing inferno. Still no time to eat. There may be time for that later. Now, more important tasks face the Forest Service team assembled at the site. Smoke fills the air. The sun beats down, causing rivulets of sweat to run down his face, washing off the sunscreen he hastily applied before leaving the plane. As he nears the fire, smoke swirls down and engulfs him, causing him to cough and burning his eyes. Maybe the wind will blow the smoke in the other direction soon. The team swings into action, cutting break lines in the underbrush. Heavy chain saws whine, emitting dust and exhaust fumes. Pulaskis are wielded, giving off a staccato uneven beat as the crew warms to the physically demanding task. The heat is intolerable. The sun beats down unmercifully, its burning ultraviolet rays reflecting off rocks and onto the unfortunate workers. As the day winds into night it is time to change shifts. The workers on this team have expended a gargantuan amount of energy, approximately 6,000 kcal on this one day alone, almost twice their normal energy expenditure. Sore muscles tighten up and inflammation grips backs, knees, shoulders and wrists. Jack is hungry, but too exhausted to eat much of the food provided. He grabs a hamburger and a piece of pie and washes them down with some lemonade. He is asleep before his head hits the pillow. This scenario will be repeated for days until his team is relieved to recover and return again if the blaze still rages. Jack is experiencing repetitive periods of oxidative stress.

Now fast-forward 25 years into the future. Jack is now nearing 60 years of age. Things are not as tough physically now, he has desk job, but he feels increasingly sore and stiff in his joints. Jack's opthamologist is concerned about something he called the 'macula' of his eye, his vision is spotty and detail is hard to make out, even with new glasses. He looks into the mirror and wonders at the number of age spots that seem to have taken residence on his face and the backs of his hands. He thinks, "Maybe I should get some of these checked out the next time I have a physical." He can remember how worried his mother was when several spots on his Dad's face were diagnosed as cancerous. He sits back in his chair and sighs as he massages his arthritic knees. "I guess I am just getting old," he thinks. I always knew it had to happen, but I didn't think it would be this soon!

Jack is correct about one thing: He is undergoing accelerated aging and is suffering from what we term (for lack of a better word) chronic disease. Chronic diseases are those maladies we often associate with the aging process, such as arthritis, macular degeneration and even some forms of cancer. Can the onset of these symptoms be delayed or even prevented? Scientists who study chronic diseases believe that many are preventable. The key seems to involve diet (Garewal 1997, Papas 1999). Epidemiologists who study the relationship between diet and disease have built a convincing case for the importance of certain nutrients contained in fruits and vegetables (McLarty 1997, Mayne and Ziegler 1999). These important nutrients are called antioxidants. Fewer than three in five Americans consume enough of them on a daily basis (Krebs-Smith et al. 1995). These antioxidant nutrients from fruits and vegetables help us control oxidative processes within our bodies that can damage important cellular components. High rates of energy expenditure, inflammation, excessive exposure to sunlight, and poor dietary habits all promote oxidative stress (Askew 1995). Severe oxidative stress can injure or kill cells (Gutteridge and Halliwell 1994). Scientists believe that excessive oxidative stress in our tissues may be at the root of many chronic diseases.

Oxidative stress is the term used to describe the damaging oxidation of biological tissues by free radicals (Gutteridge and Halliwell, 1994). Free radicals are unstable, short-lived molecules that are especially reactive chemical species because they have an unpaired electron in their outer orbit. These molecules seek to stabilize their structure (pair the electrons in their outer orbit) by "stealing an electron" from an unsuspecting neighbor (Figure 1). When this happens, the free radical is once again stable, but the molecule that lost an electron may become nonfunctional or even become a free radical itself.

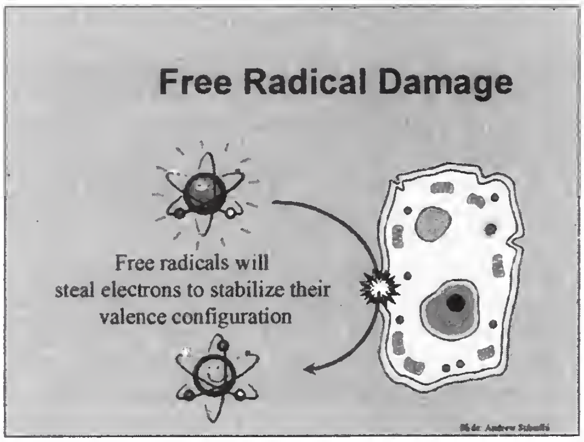

Figure 1—What is oxidative stress?

Free radicals are unstable chemical molecules that are continually being formed and destroyed in your body. They are most often oxygen-, carbon-, or nitrogen-based molecules. Oxygen molecules with unpaired electrons in their outer orbits are an especially damaging species. They are called "reactive oxygen species." Reactive oxygen species are unstable molecules containing oxygen with unpaired electrons in their outer orbit (Figure 2). Examples of reactive oxygen species are the superoxide molecule, the hydroxyl anion, and singlet molecular oxygen (Gutteridge and Halliwell 1994). Normally, oxygen molecules within the body are essential for life and are not damaging. However, a small percentage of these oxygen molecules can become potentially damaging reactive oxygen species or free radicals (Gutteridge and Halliwell 1994) . Since humans must exist in an atmosphere of oxygen and consume large quantities to survive, they have developed very effective antioxidant defense systems to neutralize these reactive oxygen species. A certain amount of free radical formation is a normal part of metabolism. Our antioxidant defense systems usually prevent free radicals from causing excessive damage.

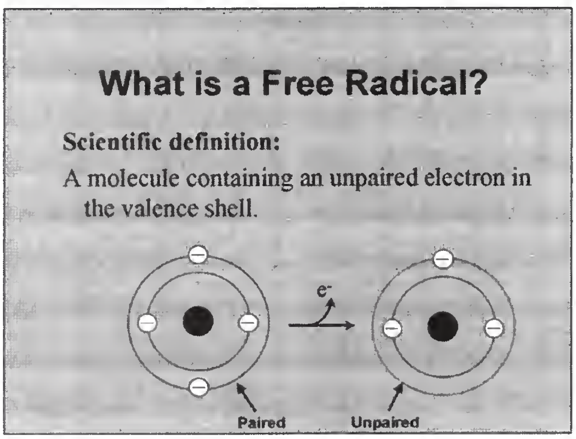

Figure 2—What are free radicals?

Certain situations or conditions are believed to lead to the formation of free radicals and increased levels of oxidative stress (Figure 3, Askew 1995). High rates of energy expenditure and their relationship to oxidative stress can be better understood by considering the analogy of "water pressure and the leaky hose." Just as more water pressure applied to a hose with a pinpoint leak causes the leak to become more pronounced, so does "metabolic pressure" (high rates of energy expenditure) cause more electrons to "leak" out of the normally tightly coupled electron transport chain into the cytoplasm of the cell where these electrons can reduce molecular oxygen to the free radical, superoxide.

Risk factors for oxidative stress:

1. **High rates of energy expenditure**
2. **Hypoxia/reoxygenation**
3. **Sunlight (UV) exposure**
4. **Inhaling atmospheric pollutants**
5. **Poor dietary intake of antioxidant nutrients**

Figure 3—Risk factors for oxidative stress.

Another theory suggests tissue that is "starved for oxygen" can suffer free radical damage when it is reoxygenated with blood that has regained its normal oxygen content. This theory is called "fanning the glowing embers," and can be likened to a smoldering coal bursting into flames when air is supplied to it. This situation might occur following exhaustive exercise at altitudes where the oxygen tension is not adequate to support the energy expenditure required.

High-energy rays found in the ultraviolet spectrum of sunlight can actually "penetrate" the dermis of skin and impart enough energy to oxygen molecules in the dermis to form a special type of "reactive oxygen species," singlet molecular oxygen. This molecule has become "excited" by the ultraviolet energy and one of its electrons has absorbed enough energy to cause it to move up into a higher orbital by itself, hence forming the potentially damaging unpaired electron configuration. Singlet molecular oxygen can "strip" electrons from cell membranes, causing internal cellular damage. Skin cancer caused by excessive sunlight exposure may get its start in this manner.

Another contributor to oxidative stress involves the biochemical processes associated with inflammation. Phagocytotic cells rushing to the site of damaged or injured tissue can release substantial amounts of free radicals in the process of fighting infection and inflammation.

Inhalation of toxic compounds in the air we breathe may also give rise to free radical production (Figure 4). Smoke is particularly irritating to the lungs and may be damaging due to increased free radical formation (Gutteridge and Halliwell 1994). Most of the evidence for the damaging effects of acute and chronic smoke inhalation come from studies of tobacco smoking, but inhaling smoke from a forest fire might be expected to elicit acute responses similar to (but less chronic than) cigarette smoking. Little data exists to confirm or deny smoke inhalation as a high risk item for wildland firefighters. Sharkey (1997a) has recommended a prudent approach that firefighters avoid smoke exposure and eat a diet including antioxidant foods to maintain a healthy immune system.

Smoke

- Smoke contains free radicals (oxides of nitrogen $NO\cdot$ & $NO_2\cdot$) in both the gas and tar phases which irritate lung membranes
- Chronic smoke inhalation causes tissue inflammation which in turn leads to macrophage and neutrophil infiltration of the lungs
- Acute smoke inhalation and bacteria in the inflamed tissue stimulates neutrophils to produce superoxide ($O_2\cdot-$)
- $O_2\cdot-$ and $NO_2\cdot$ can lead to lung tissue damage

Figure 4—Smoke and free radicals.

The good news is that the human body is remarkably well equipped to minimize oxidative stress caused by free radical damage (Figure 5), provided we do our part. We must provide the our body with the "biological flame retardants" or antioxidant nutrients that it needs to neutralize free radicals. Antioxidant nutrients can be minerals, vitamins, or plant phytochemicals. The minerals zinc, selenium, magnesium, and manganese function as important nutrient cofactors or "helpers" for enzymes such as superoxide dismutase and glutathione reductase. These minerals and enzymes work in a concerted manner to neutralize free radicals such as superoxide. Left unchecked, these bad characters can strip electrons from unsuspecting cellular component neighbors, leading to leaky cell membranes, nonfunctional enzyme proteins, and even coding errors in DNA molecules.

Antioxidant Defense Systems:

The body's "firefighters"

- **Antioxidant enzymes**
- **Antioxidant vitamins**
- **Phytochemicals from fruits and vegetables**

Figure 5—Antioxidant defense systems.

Antioxidant enzymes are fast acting and very effective as long as the level of invading free radicals is not excessive. When severe oxidative stress is present and the antioxidant enzymes are overwhelmed by the invading free radicals, the antioxidant vitamins and antioxidant phytochemicals become the last line of defense between our cells and free radical damage. The large, complex molecules of antioxidant vitamins and phytochemicals can directly interact with a free radical and "neutralize" it by absorbing the full force of its attack, much as a sumo wrestler would envelop a smaller foe. The antioxidants neutralize free

radicals by donating an electron to stabilize the free radical. Unlike smaller molecules that may be attacked by a free radical, these large organic, antioxidant molecules "internalize" the loss of an electron through resonance between carbon bonds. They do not themselves become electron-seeking free radicals. Some antioxidant vitamins such as vitamin E (alpha-tocopherol) and vitamin C (ascorbate) act as "tag team" partners to intercept and neutralize free radicals. Vitamin E is lipid soluble and can position itself in the membrane of cells and lipoproteins where it can "intercept" free radicals that attack lipid-containing cell membranes. Once vitamin E has intercepted a free radical, it can pass the "hit" to water-soluble vitamin C. In this manner, vitamin C regenerates the immobile vitamin E in the membrane and can, in turn, be regenerated by other antioxidant phytochemicals in the cell or pass out of the cell, into the blood and ultimately be excreted in the urine.

Phytochemicals are molecules of plant origin (such as carotenoids, flavenoids, phytosterols, chlorophylls, terpenoids, indoles and allylic compounds) consumed in the diet that are not true vitamins, but can be very potent antioxidant nutrients (Papas 1999). Plants have evolved very sophisticated mechanisms to protect themselves from the large amount of oxygen generated by photosynthesis. The conversion of even small quantities of that oxygen to free radicals would potentially be lethal to the plant (Halliwell and Gutteridge 1993). We gain the protective effect of these powerful antioxidant phytochemicals when we consume fruits and vegetables. Five servings of fruits and vegetables per day supply us with enough of these antioxidants to prevent or combat many chronic diseases such as cancer and macular degeneration (Block et al. 1992).

However, active people working in remote outdoor environments usually do not have access to ample quantities of fresh fruits and vegetables (Askew 1995). The National Cancer Institute and other agencies concerned with disease prevention recommend eating five servings of fruits and vegetables per day. In fact, many persons do not even consume five servings of fruits and vegetables per day when they are eating at home, close to the local supermarket (Krebs-Smith et al. 1995). This information does not diminish the importance of diet, but strengthens the case for supplementing the diet with antioxidant nutrients for people who might be subject to increased oxidative stress.

How can we tell if someone is experiencing "too much" oxidative stress? Much as criminals may leave "fingerprints" at the scene of a crime, free radicals leave a trail of cellular damage that can be detected as fragments of damaged lipids, proteins, and DNA. We can look for these "damage indicator fragments" in breath, blood, and urine (Figure 6). Biondicators of oxidative stress can be used to establish the need for additional dietary antioxidants as well as the optimal intake of these antioxidants (Halliwell 1999). Elevated levels of these bioindicators usually mean that the body needs "reinforcements" in its battle against free radicals. These "reinforcements" are usually dietary antioxidants that can come from food or from antioxidant supplements.

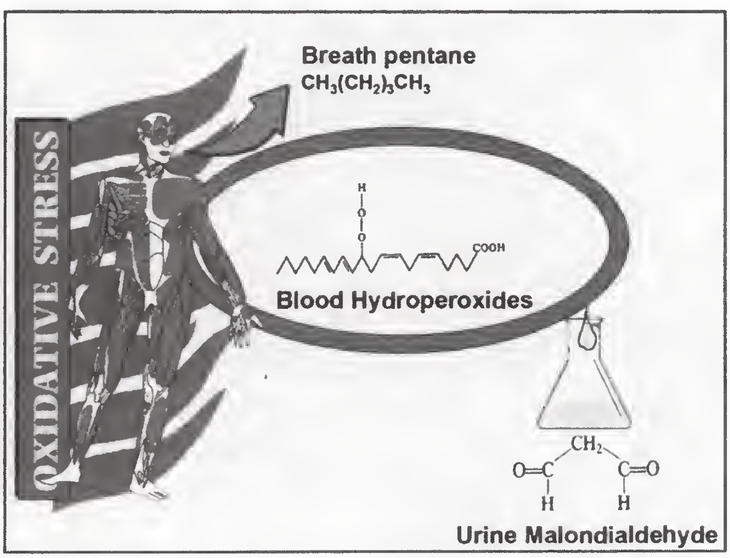

Figure 6—Bio-indicators of oxidative stress.

The Forest Service has recognized that physical fitness and diet are important components of maintaining firefighter health and safety (Sharkey 1997b). Wildland firefighters expend large quantities of energy in an environment containing atmospheric pollutants from burning vegetative material. They may experience intermittent or altered dietary patterns while fighting fires. Research involving occupational specialties that share oxidative stress risk factors similar to firefighters (a diet low in fruits and vegetables, high levels of physical exertion, sunlight exposure, and smoke inhalation) leads us to predict that firefighters may also experience increased free radical formation and therefore might benefit from antioxidant supplementation (Figure 7). Certain types of military training are similar to the rigors of wildland firefighting. Preliminary studies of U.S. Army Ranger training and U.S. Marine Mountain Warfare training indicate that these individuals may be under increased levels of oxidative stress and might benefit from supplemental antioxidants (Shippee 1999, Pfeiffer et al. 1999, Chao et al. 1999).

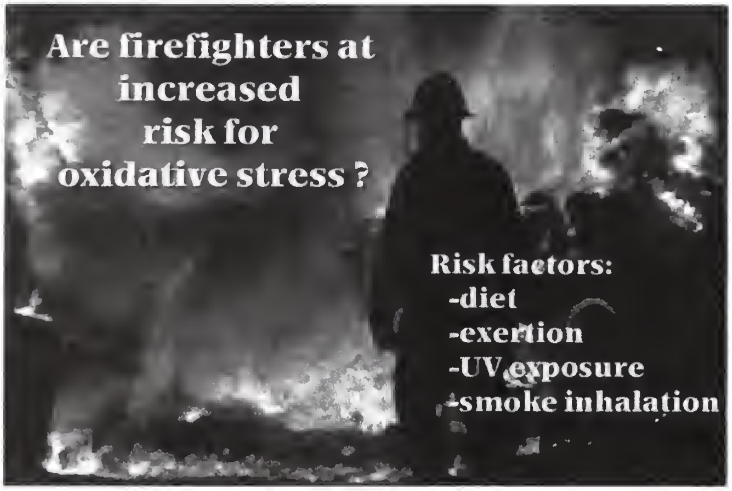

Figure 7—Are firefighters at increased risk for oxidative stress?

Research is needed to establish if wildland firefighters are indeed under excessive levels of oxidative stress and to investigate their response to supplemental antioxidants. Until such research can be accomplished, it is advisable to take a conservative approach that includes both diet and exercise as preventive measures (Figure 8). As recommended in the USDA Forest Service

What can I do to lower my level of oxidative stress?

Exercise training
•Boosts levels of antioxidant enzymes

Diet
•Five servings of fruits and vegetables per day

Dietary Supplements
•Vitamins A (beta carotene) C, & E
•Phytochemical antioxidant supplement

Figure 8—Recommendations to lower oxidative stress levels in firefighters.

report, “Fitness and Work Capacity” (Sharkey 1997b), firefighters should be in excellent physical condition, participate in regular aerobic and strength training, and pay close attention to their diet. These steps will ensure high levels of antioxidant defense enzymes and nutrients in their tissues. Their normal diet should include at least five servings of fruits and vegetables each day. During extended periods of training or actual firefighting, the catering service should be encouraged to supply foods that contain high levels of antioxidant nutrients. Fruits, fruit juices, and vegetable juices are appealing to most people even under adverse field conditions and are good sources of antioxidant nutrients. Serious consideration should be given to providing supplemental antioxidants during field training and firefighting. These supplements could be provided in beverage or tablet form. The potential for antioxidant supplementation to cause harm is low. Supplementation has significant potential short- and long-term benefits. A possible exception may be heavy cigarette smokers, who should avoid supplements containing high levels of beta carotene, due to its association with increased risk of cancer (Diplock 1997).

Firefighters share many of the risk factors that are associated with increased oxidative stress in other populations (Figure 9). Research to directly document the influence these risk factors on firefighter health is lacking. Until such research is accomplished, a prudent and conservative approach should be adopted to emphasize increased dietary and possibly supplemental intake of antioxidant nutrients for firefighters.

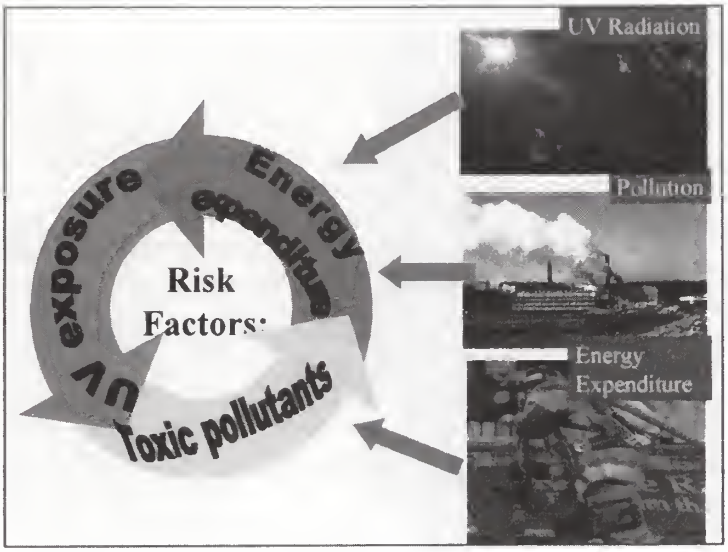

Figure 9—Summary of risk factors.

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Individual Factors Related to Health, Safety, and Performance

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The ability to perform hard (arduous) work for protracted periods of time can be related to a number of physical and psychological factors. These factors can override demographic factors such as gender, race, or ethnicity. Some of these factors, listed in no particular order of importance, are:

- Physical size and body composition
  - Lean body weight
  - Fat weight
- Personal fitness and fitness factors
  - Strength
  - Stamina
  - Muscular endurance
  - Acclimatization
- Motivation
- Nutritional Status
  - Hydration
  - Energy substrates
- Age
- Psychological state (fatigue)
- Overall health status (wellness)

Some of these factors are controllable, others are inherited, and still others change with the environment. Recognizing that we have no control over the environment, what factors can we address?

With all of the published research on the benefits of regular exercise, you would think that people would embrace the concept that the human body was meant to be used. While we can't guarantee that there's a one-for-one relationship between fitness and longevity, for fit persons the quality of the life is clearly more vibrant and productive. The direct benefits to increased productivity on the job is well documented.

We might ask the same question of the well-established relationship between smoking and a host of diseases and disorders. Knowing what we do, why do people choose to do the things they do? Said another way, the physiological basis for improving performance and health is well known. What's really needed is more research on how to motivate people to avoid self-destructive behavior such as smoking or sedentary lifestyles.

In terms of demographic factors, research does not lend support to physical performance limitations based on race or ethnicity. Studies of gender differences indicate the obvious: women are, on average, smaller than men, and they have much less upper body strength (50 to 60% of the upper body strength of men). The average woman has a lower aerobic fitness (39 to 40 ml/kg-min for young women compared to 45 to 48 ml/kg-min for men. This means that when job demands are arduous, as they are for wildland firefighters, more women will have to train to be able to accomplish work tasks, while maintaining a reserve to meet unforeseen emergencies.

Age

For the balance of this paper, I would like to examine a topic that has been of great personal interest to me: aging. Aging is relevant because all of us are on this planet together, and no one is getting off alive. We all have the same amount of time per day. We are basically captives of the 24-hour day.

Age has been used in making hiring decisions for many years. The Age Discrimination in Employment Act (ADEA) developed a protected class (persons from 40 to 70 years old). For persons within the portected class, employers could only use age for decision-making when they could show that it constituted a BFOQ (bona fide occupational qualification). Most of us operate on the principle that there is a decline in performance with advancing age. This is true. No one reverses the aging process, no matter what you may hear. But, we can certainly slow and temporarily halt the process by adhering to a well-established scientific principle called the General Adaptation Syndrome (GAS).

What the GAS says is that if you don't use a certain physiological system, you lose it. Conversely, if you use a system, it gets stronger. This is the underpinning of physical conditioning. If we stress a system to the point of fatigue, it rebounds and actually becomes stronger. Clearly, there are limits. All Olympic athletes strive to optimize all of their systems, allowing them to perform beyond any previously demonstrated level.

So what are the implications for wildland firefighters? Looking again at the factors that have been demonstrated to distinguish differences in work output and personal performance, alterations and improvements can be shown in the following areas:

- Physical size and body composition
  Lean body weight is increased through physical exercise (strength or resistance training)
  Fat weight (both total percent fat and total fat weight) is reduced, resulting in less " dead weight" to be hauled around, reducing the burden on the heart to pump blood or otherwise support mass that is not contributing to productivity)
- Personal fitness and fitness factors
  Strength: If I train the neuromuscular system, then I will get stronger. Lifting objects now takes less of my functional reserve.
  Stamina: Cardiovascular fitness (the ability to take up and utilize oxygen) has a host of benefits beyond the simple improvement of one's functional work capacity. Training the cardiovascular system sets in motion a host of positive effects such as lowered heart rate while at rest or while performing sustained tasks that previously resulted in fatigue.
- Muscular endurance
  Muscular endurance (not to be confused with heart-fitness) are those repetitive muscle-contractions that are typically finite in nature (we usually measure them in repetitions to failure). Adaptations from training in this area are among the fastest to improve and the easiest to sustain.
- Acclimatization
  The body adjusts to the effects of heat and altitude.
- Motivation
  The fitter individuals have already demonstrated that they are personally motivated. They feel that they have a locus of control that starts within themselves. Think of it this way: they know how to budget time and have organized their day to include personal time that directly benefits them.
- Nutritional Status
  Hydration: No matter how fit you are, when you're out of fluid, you're out of gas. Paying attention to personal hydration status is critical. There may be no edge for the fit person, other than, hopefully, they've learned that you need a minimum of 1 quart of fluid for every 60 minutes of hard work.

  Energy substrates: The fit person is better able to store (supersaturate) fuel at the cell level than the unadapted individual. Again, score another point for the fit person.
- Age
  Medical science has amassed evidence that individuals may actually "choose not to age." Said another way, while you can't stop the superficial process of graying hair or the wrinkling skin, you can preserve and extend your underlying "functional work capacity." The human organism is a wonderful machine that, unlike man-made machines, is better maintained with use.

  The normal age-associated decline in aerobic fitness, one important dimension of firefighter fitness, is approximately 1% per year, or 10% per decade for the sedentary population. In physically active individuals, the loss is approximately 13% across the span of 25 years.

  In a study funded by the U.S. Fire Administration examining the relationship between physical performance measures and job performance, increasing amounts of body fat were more harmful to performance than was advancing age.

- Psychological state (fatigue)
  We all need sleep and rest; without rest, work performance goes down markedly and ultimately halts. The fit person can do more work in less time and takes less time to recover.
- Overall health status (wellness)
  Wellness is a term that lacks objectivity. We can't measure it in terms like pounds, or milliliters per minute. But the fit individual has a certain vibrancy, resistance to fatigue, resistance to disease and savior-faire. If you've been there then you know what I'm talking about. If you haven't, then the good news is that you can experience the personal benefits of fitness. It's a challenge that's available to everyone walking the face of the earth.
- Ethnicity and race
  Laboratory or field studies do not support differences in performance related to ethnicity or race.
- Gender
  Because of factors such as body size (lean body weight), and muscular and aerobic fitness, some men and women will have to train to meet job demands.

In Summary

- The job of firefighter does not change as a consequence of advancing age (the fire doesn't know or care who's making the attack).
- Aging is inevitable, but the loss of physical work capacity is significantly diminished through regular programs of physical activity.
- The use of a physical performance tests can answer the question " Can you still safely perform the essential functions of the job?"
- It is possible for firefighters to maintain the capacity to perform arduous work into their 60's; however, this will not occur without regular exercise as a part of their lifestyle.
- Individuals who meet only minimum levels of fitness upon entering a firefighting career are not likely to realize a service-connected retirement.

> *Youth is not a time of life, it is a state of mind. It is not a matter of rosy cheeks and supple knees but a matter of will, a quality of imagination, a vigor of emotions, an appetite for adventure over the love of ease. This often exists in the man of 60 more than in the boy of 20.*
>
> Samuel Ullman

Conference Program

Mon. 4/26

1800	Arrive, register, informal social	

Tues. 4/27

0800	Registration	
0830	Welcome	Brian Sharkey, MTDC
0840	Director's Perspective	Jose Cruz, F&AM
0900	Defining the Issues:	Dick Mangan, MTDC, Dave Aldrich, F&AM
0930	**Session 1.**	**Firefighter Health and Safety**
0930	Presentation:	**Illness, Injuries, and Fatalities** Dick Mangan, MTDC
1000	Break	
1020	Panel	**What We Need to Know About Illness, Injuries, and Fatalities** D. Mangan, Ron Wilson, Chuck Whitlock, MTDC
1100	Discussion:	**Ways to Reduce Illness, Injuries, and Fatalities**
1145	Lunch	
1300	**Session 2.**	**Job Requirements/Issues**
1300	Presentation:	**Demands of the Job** Brian Sharkey, Ph.D., MTDC
1330	Presentation:	**Energy Demands of Wildland Firefighting** Brent Ruby, Ph.D., U of Montana
1400	Panel:	**What We Need to Know About Work-Related Issues and Health** B. Ruby, B. Sharkey, Leslie Anderson, Steve Karkanen
1430	Discussion:	**Should Job Requirements Be Changed?**
1500	Break	
1520		**Presentations, Posters, and Products**
1700	Adjourn	
1900		Informal discussions among participants

Wed. 4/28

0800 Session 3. The Working Environment

0800 Presentation: **Heat Stress**
Brian Sharkey, Ph.D., MTDC

0830 Presentation: **Health Hazards of Smoke**
NWCG Video

0900 Panel: **What We Need to Know About the Working Environment**
B. Sharkey, B. Ruby, Roger Ottmar, Dave Custer

0930 Discussion: **What Can We Do to Improve the Working Environment?**

1000 Break

1020 Session 4 Factors That Influence Health

1020 Presentation: **Firefighting and the Immune Response**
Steve Wood, Ph.D., Ross Laboratories

1050 Presentation: **Oxidative Stress in Firefighting**
Wayne Askew, Ph.D., U of Utah

1120 Panel: **What We Need to Know About Firefighter Health**
W. Askew, S. Wood, Mark Vore, Paul Broyles

1200 Lunch

1300 Discussion: **What Can Be Done to Ensure Firefighter Health?**

1330 Session 5 Factors Related to Health, Safety, and Productivity

1330 Presentation: **Individual Factors Related to Health, Safety, and Productivity**
Paul Davis, Ph.D., Applied Research Associates

1400 Panel: **Ways to Improve Health, Safety, and Productivity**
P. Davis, Becky Livingstone, Teresa Bellinger, Ph.D.

1430 Discussion **Issues Related to Individual Factors**

1500 Break

1520 Working Groups: Organization and ground rules:
Avoiding illness, injuries, and fatalities
Job requirements/issues (shift length, work/rest guidelines)
The working environment (heat, smoke, uniforms, tools)
Nutrition/energy
Individual Factors (gender, age, fitness)

1600 Working Groups: Initial meeting

1700 Adjourn

Thurs. 4/29

0800 Announcements

0810 Working Groups: Meet to discuss/develop specific recommendations

1000 Break

1020 Combined Groups: Review progress

1100 Working Groups: Finalize recommendations

1200 Lunch

1300 **Combined Groups: Meet to prioritize recommendations in areas of:**
Research and development
Environmental safeguards, uniforms, PPE
Nutritional guidelines, supplements, catering contracts
Work/rest, shift length, and other guidelines
Health habits, stress management
Employee selection/training
Medical screening

1600 Adjourn

Thurs. p.m.
Fri. a.m. Optional Tours: Smokejumper Training Center (Tony Petrilli)
Intermountain Fire Sciences Laboratory
University of Montana Human Performance Lab (Dr. Ruby)

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Brian Sharkey completed a Ph.D. in exercise physiology at the University of Maryland before coming west to join the faculty of the University of Montana and begin a long association with MTDC. His work for the Forest Service has included research and development on fitness tests and programs, heat stress, hydration, nutrition, protective clothing, tools, work/rest cycles, employee health (wellness), and more.

A researcher, author of several books, and past president of the American College of Sports Medicine, Dr. Sharkey practices what he preaches, participating regularly in running, mountain biking, cross-country skiing, backpacking, canoeing, and other pursuits. His work has recently been honored with a USDA Distinguished Service Award, and a Forest Service Technology Transfer Award.

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Sharkey, Brian, ed. 1999. Wildland firefighter health and safety: recommendations of the consensus conference, April 1999. Tech. Rep. 9951-2841-MTDC. Missoula, MT: U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center. 74 p.

Presents the recommendations and key papers from a conference on wildland firefighter health and safety held in Missoula, MT, from April 27 to 29, 1999. Topics covered during the conference included: firefighter health and safety, job requirements and issues, the working environment, factors that influence health, and factors related to health, safety, and productivity.

Keywords: fire fighters, fire fighting, heat stress, illness, immune response, job performance, occupational health, safety at work

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